

NAVAL POSTGRADUATE SCHOOL MONTEREY, CALIFORNIA



THESIS

AN ANALYSIS OF EMERGING COMMERCIAL WIDE
BAND SATELLITE SYSTEM AND THEIR POTENTIAL
FOR MILITARY USE

by

Lee, Tin Hua

March 1999

Thesis Advisor:
Second Reader:

Brij N. Agrawal
Craig Baldwin

Approved for public release; distribution is unlimited.

DTIC QUALITY INSPECTED 1

19990325 055

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
March 1999

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE

AN ANALYSIS OF EMERGING COMMERCIAL WIDE BAND SATELLITE SYSTEM AND THEIR POTENTIAL FOR MILITARY USE

5. FUNDING NUMBERS

6. AUTHOR(S)

Lee, Tin Hua

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION
REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING
AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

Spurred by the growing need of information transfer around the globe, considerable investment is being made in the private sector to develop and field new commercial SATCOM services. From the military perspective, the exploitation of this commercially developed SATCOM services becomes an attractive augmentation to expensive MILSATCOM programs especially in an era of declining defense dollars. Applications such as battlefield situational awareness, operational planning and execution, weather, telemedicine, operations and maintenance support, tailored intelligence, distance learning, training, morale, welfare and recreation services are areas where emerging commercial wide-band satellite systems such as Teledesic, Skybridge, Cyberstar, Astrolink and Spaceway might offer possible solutions.

This thesis analyzes these five commercial satellite systems in terms of their performance measures derived from the seven required characteristics as defined in the Advanced MILSATCOM Capstone Requirement Document [Ref. 7]. In addition, factors that might account for the commercial viability of these systems are also considered to determine their survivability in this competitive market place. A portion of this thesis has also been devoted to illustrate current MILSATCOM architecture so as to give reader an appreciation of the present capabilities, life spans and the possible future architecture that it might take.

14. SUBJECT TERMS

MILSATCOM, commercial wideband SATCOM

15. NUMBER OF PAGES

106

16. PRICE CODE

17. SECURITY
CLASSIFICATION OF
REPORT

Unclassified

18. SECURITY CLASSIFICATION OF
THIS PAGE

Unclassified

19. SECURITY CLASSIFI- CATION
OF ABSTRACT

Unclassified

20. LIMITATION OF
ABSTRACT

UL

Approved for public release; distribution is unlimited

**AN ANALYSIS OF EMERGING COMMERCIAL WIDE BAND SATELLITE
SYSTEM AND THEIR POTENTIAL FOR MILITARY USE**

Lee, Tin Hua
Major, Singapore Army
B.Eng. , University of Surrey, U.K., 1993

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
March 1999

Author: _____

Lee, Tin Hua

Approved by: _____

Brij.N. Agrawal, Thesis Advisor

Craig Baldwin, Second Reader

Don Boger, Chairman

Information Warfare Academic Group

ABSTRACT

Spurred by the growing need of information transfer around the globe, considerable investment is being made in the private sector to develop and field new commercial SATCOM services. From the military perspective, the exploitation of this commercially developed SATCOM services becomes an attractive augmentation to expensive MILSATCOM programs especially in an era of declining defense dollars. Applications such as battlefield situational awareness, operational planning and execution, weather, telemedicine, operations and maintenance support, tailored intelligence, distance learning, training, morale, welfare and recreation services are areas where emerging commercial wide-band satellite systems such as Teledesic, Skybridge, Cyberstar, Astrolink and Spaceway might offer possible solutions.

This thesis analyzes these five commercial satellite systems in terms of their performance measures derived from the seven required characteristics as defined in the Advanced MILSATCOM Capstone Requirement Document [Ref. 7]. In addition, factors that might account for the commercial viability of these systems are also considered to determine their survivability in this competitive market place. A portion of this thesis has also been devoted to illustrate current MILSATCOM architecture so as to give reader an appreciation of the present capabilities, life spans and the possible future architecture that it might take.

TABLE OF CONTENTS

I. INTRODUCTION	1
A. BACKGROUND	1
B. PURPOSE.....	2
C. ORGANIZATION	2
II. DOD WIDE-BAND SATELLITE COMMUNICATION REQUIREMENTS	3
A. INTRODUCTION	3
B. MILSATCOM CAPSTONE REQUIREMENT DOCUMENT	3
1. <i>The Seven characteristics of CRD</i>	4
a. Coverage.....	6
b. Capacity (Throughput).....	8
c. Protection.....	9
d. Access and Control	11
e. Interoperability	12
f. Flexibility	13
g. Quality of Service	15
2. <i>Commercial Viability</i>	16
a. Regulatory approval.....	16
b. Funding and Corporate Backing	17
c. Market Acceptance and Access	18
d. Technical Feasibility.....	18
C. SUMMARY.....	18
III. OVERVIEW OF CURRENT DOD COMMUNICATION SATELLITE CONSTELLATION	21
A. CURRENT ARCHITECTURE	21
1. <i>The (SHF) Defense Satellite Communications System (DSCS)</i>	22
2. <i>EHF Military Strategic Tactical And Relay (MILSTAR)</i>	24
3. <i>Ultra High Frequency (UHF) satellites</i>	26
4. <i>Global Broadcast Service (GBS) Program</i>	28
5. <i>Leased Commercial Satellite Services</i>	29
a. INMARSAT	29
b. INTELSAT	31
B. FUTURE MILSATCOM ARCHITECTURE.....	34
IV. COMMERCIAL WIDE-BAND SATELLITE COMMUNICATION SYSTEM	39
A. INTRODUCTION	39
B. OVERVIEW OF COMMERCIAL SYSTEM	39
1. <i>Satellite orbits</i>	39
2. <i>Frequency and Spectrum Consideration</i>	43
3. <i>Inter-Satellite link</i>	46
4. <i>Frequency Reuse</i>	47
5. <i>Access Methods</i>	47
6. <i>Pricing</i>	49
7. <i>Market Strategy</i>	50
8. <i>Security and Global Billing</i>	51
C. POSSIBLE CANDIDATES.....	53
1. <i>Teledesic</i>	53
2. <i>Spaceway</i>	56
3. <i>Astrolink</i>	58
4. <i>Cyberstar</i>	59
5. <i>Skybridge</i>	61

D. SUMMARY.....	63
V. ASSESSMENT OF CANDIDATE SYSTEMS.....	69
A. INTRODUCTION.....	69
B. ACCESS AND CONTROL.....	70
C. COVERAGE.....	71
D. INTEROPERABILITY.....	72
E. REGULATORY APPROVAL.....	73
F. MARKET ACCEPTANCE.....	74
G. QUALITY OF SERVICE (QOS).....	76
H. CAPACITY.....	77
I. TECHNICAL FEASIBILITY AND COST OF SYSTEM.....	79
J. SUMMARY.....	81
VI. CONCLUSIONS.....	83
A. POTENTIAL MISSION.....	83
B. LIMITATIONS AND RECOMMENDATIONS.....	85
LIST OF REFERENCES	89
BIBLIOGRAPHY	91
INITIAL DISTRIBUTION LIST	93

LIST OF FIGURES

Figure 1. Dod Satcom Mission Life Time From Ref. [2].....	1
Figure 2. Current MILSATCOM Architecture From Ref. [3]	21
Figure 3. Projected SATCOM capacity from [Ref. 5]	34
Figure 4. MILSATCOM Course of Action from [Ref. 6].....	35
Figure 5. Future MILSATCOM Architecture from [Ref. 3].....	37
Figure 6. Summary of Frequency band from [Ref. 12]	44
Figure 7. The Teledesic's LEO satellite from [Ref. 15].....	53
Figure 8. The area covered by a satellite at height h with elevation angle ϵ from [Ref.17].....	78
Figure 9. Media Mix Requirements Allocation from [Ref.12].....	86

LIST OF TABLES

Table 1a. Summary of CRD requirements and performance attributes	4
Table 1b. Summary of CRD requirements and performance attributes	5
Table 1c. Summary of CRD requirements and performance attributes	6
Table 2. Cross reference matrix for accessing emerging Wide band satellite systems	19
Table 3. Summary of DSCS from [Ref. 4]	24
Table 4. Summary of Milstar from [Ref. 4]	26
Table 5. Summary of UHF Follow-on from [Ref. 4]	27
Table 6. Summary of INMARSAT after [Ref. 4]	31
Table 7. Summary of INTELSAT after [Ref. 9 & 10]	34
Table 8. Chief differences between 3 types of satellites	42
Table 9. Advantages and Disadvantages of Access Methods from [Ref. 13]	49
Table 10. Teledesic Timeline	54
Table 11. Family of Spaceway terminal	57
Table 12. Astrolink customer bandwidth and terminal options	58
Table 13. Summary of Commercial Wideband Satellite System	64
Table 14. Evaluation of capability to support the requirements	69
Table 15. Access and Control ranking	71
Table 16. Coverage ranking	72
Table 17. Interoperability ranking	73
Table 18. Regulatory approval ranking	74
Table 19. Market Acceptance ranking	75
Table 20. Quality of service ranking	77
Table 21. Capacity ranking	79
Table 22. Ranking with respect to Technical feasibility and cost of system	81
Table 23. System ranking	82

I. INTRODUCTION

A. BACKGROUND

It has been projected by 2000, 150-million households [Ref. 1] using the Internet will demand high quality text, voice, data and video communication services throughout the world. As a result, satellite manufacturers and service providers are investing heavily to develop and field commercial wide-band¹ high capacity multimedia satellite communication systems as part of an effort to capture an estimated US\$10 trillion market (based on the aggregated global demand for telecommunications over the next decade). In an era of declining defense dollars, the exploitation of this commercially developed technology becomes an attractive alternative or augmentation to expensive MILSATCOM programs in anticipation of current DOD owned SATCOM reaching their mission life time in the 2004 to 2006 time frame and the needs to address the replenishment systems in the 2004 to 2015 time frame.

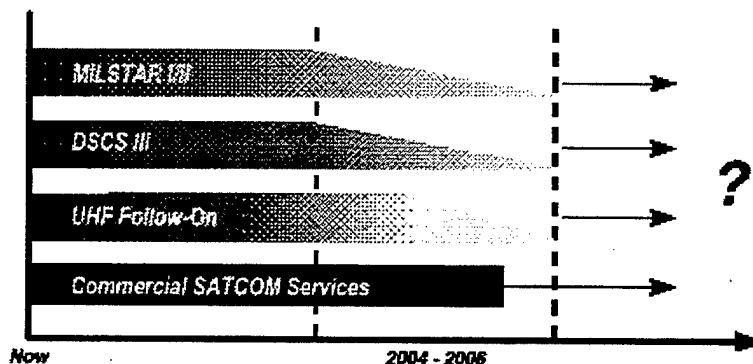


Figure 1. DOD Satcom Mission Life Time From Ref. [2]

However, the challenge is while exploiting this potential, decision to take advantage of these systems must be tempered by their inherent vulnerabilities. Thus, the balancing of military requirements with the cost saving of using current and projected commercial technology is one of the crucial factors in addressing the ever increasing reliance on information transfer to maintain command, control efficiency and battlespace awareness in this information age.

¹ Wideband – High capacity circuits and networks in excess of 64 Kbps.

B. PURPOSE

This thesis is to examine emerging commercial wide-band satellite communication system architectures used to support fixed and mobile² users. In particular, focus will be on DOD basic warfighting requirements and to identify emerging commercial satellite communication systems that can satisfy these requirements. Each system will be analyzed with respect to cost; performance, coverage, availability and vulnerability as they relate to projected DOD user requirements.

C. ORGANIZATION

This thesis is divided into six chapters. A short description of each chapter is provided below.

- Chapter I. Introduction. - Addressing purpose, background and organization of this thesis.
- Chapter II. Overview of DOD wide-band satellite communication requirements based on the MILSATCOM Capstone Requirement Document (CRD) and Mobile User SATCOM Study (MUS)
- Chapter III. Overview of current DOD satellite constellation and mission life spans including INMARSAT and INTELSAT.
- Chapter IV. Overview of emerging commercial wide-band satellite systems. – Addressing their capabilities, affordability, limitations, system weaknesses and concept of operations.
- Chapter V. Assessment of five possible candidate systems, namely Astrolink, Teledesic, Spaceway, Cyberstar and Skybridge based on requirements delineated in Chapter II and with consideration of their commercial viability.
- Chapter VI. Conclusions and recommendations.

² Mobile denotes a "communication on the move" capability. This includes but not limited to ships at sea, aircraft, wheeled units and any other application that will allow personnel to communicate without having to stop and setup antennas or other hardware.

II. DOD WIDE-BAND SATELLITE COMMUNICATION REQUIREMENTS

A. INTRODUCTION

The goal of this research is to evaluate emerging commercial wide-band satellite systems/services and their potential for DOD use. This chapter extracted the basic characteristics or requirements from the thesis [Ref. 7] written by Darin L. Powers (which is based on DOD's MILSATCOM Capstone requirement document) and Mobile User Study [Ref. 8] as a means for comparing different systems and identifying which are the ones that satisfy DOD communication requirement the best. In-addition, as some of the wide-band systems are still in the developmental stage and not all will have attained operation, therefore a selection of candidates for DOD consideration should also consider the probable success of their commercial viability. However, with a "paper concept" and as the information involved is mostly proprietary, this research study will only conduct an initial screening based on what is publicly available. Some of the key factors will be discussed in the following sections of this chapter.

B. MILSATCOM CAPSTONE REQUIREMENT DOCUMENT

The MILSATCOM Capstone Requirement Document (CRD) was developed by CINCSpace as directed by the Deputy Under Secretary of Defense (OA&T) to address DOD's need for increased satellite communication capabilities and capacity. In-addition the CRD also defines top level characteristics for the overall system-of-system MILSATCOM architecture. These characteristics were vetted through a group of senior officials called the Senior Warfighter's Forum (SWarF) and approved and validated by JROC in 1998. Thus the CRD will not only guide the development of future MILSATCOM ORDs (Operation Requirement Documents) but it also sets the performance goals which DOD's future MILSATCOM programs and commercial services should strive to achieve within available funding.

1. The Seven characteristics of CRD

The CRD defines seven required characteristics as The Joint Wide Capstone Requirements that apply to all types of SATCOM. For the purpose of this research study, a set of performance attributes is derived from these seven requirements against which the emerging commercial wide-band satellite systems/services are evaluated in subsequent chapters. The requirements/characteristics are listed as follows:

REQUIREMENTS	CRD FUNCTIONAL OBJECTIVES	PERFORMANCE ATTRIBUTES
COVERAGE	<ul style="list-style-type: none"> • Ability to provide MILSATCOM when/where needed at all latitudes and Longitudes 	<ul style="list-style-type: none"> • Provides continuous service from 65N to 65S and the 2 polar regions without gaps in geographical coverage • Short delivery time • Low time to set up service • Support high dynamic platforms • Small Terminals and Antennas • Combat environment conditions <ul style="list-style-type: none"> • Building • Double canopy environment • Rain rate "H" • Sea environment
CAPACITY	<ul style="list-style-type: none"> • Ability to provide requisite amounts of wide-band and narrow band capabilities (throughputs and accesses) to war-fighters and their infrastructures: • Wide-band (Symmetric, asymmetric and broadcast) • Narrow-band (netted and other topologies) 	<ul style="list-style-type: none"> • Dedicated circuit • Data rate • Bit Error rate • Overall system capacity

Table 1a. Summary of CRD requirements and performance attributes

REQUIREMENTS	CRD FUNCTIONAL OBJECTIVES	PERFORMANCE ATTRIBUTES
PROTECTION	<ul style="list-style-type: none"> • Ability to provide levels of protection to sub-sets of the overall MILSATCOM capacities: <ul style="list-style-type: none"> • Survivable and anti-jam communications for NCA/SIOP forces • Anti-jam for "front line" C2 and common user networks • LPI/LPD for critical tactical and strategic covert/sensitive users • US Control for selected users (e.g. vital diplomatic and intelligence needs and selected tactical) 	<ul style="list-style-type: none"> • Protection of information on user location • Protection from Signal exploitation • Compatible with DOD COMSEC • Prevent unauthorized access to, or disclosure of information that includes: <ul style="list-style-type: none"> • Confidentiality • Authenticity • Data integrity
ACCESS AND CONTROL	<ul style="list-style-type: none"> • Ability to dictate resource utilization over apportioned resources and can plan, allocate, and schedule access within fractions of hours to few hours. • Resources can be rapidly and dynamically configured and re-configured within a few hours to fraction of hours (selected networks within minutes) • Near real time authorization, denial, preemption of access 	<ul style="list-style-type: none"> • Prioritization and Preemption • US control • Vendor's relationship with US • Dedicated circuit • Access on demand
INTER-OPERABILITY	<ul style="list-style-type: none"> • Interoperability between/ among CINC and JTF components (e.g. Land, Air, Naval, Mobility Combat support, Special Operations forces, allies and coalition partners and other US government agencies • Provide seamless Terrestrial to Satellite Information transfer • Capability to effect Information transfer between Commercial and Military means 	<ul style="list-style-type: none"> • PSTN interface • DISN interface • Compatible with DOD COMSEC • Interoperable with other vendor's system

Table 1b. Summary of CRD requirements and performance attributes

REQUIREMENTS	CRD FUNCTIONAL OBJECTIVES	PERFORMANCE ATTRIBUTES
FLEXIBILITY	<ul style="list-style-type: none"> • Ability to accommodate evolving doctrine, requirements, threats and technologies. Emphasis is on fast-paced mobile operation. 	<ul style="list-style-type: none"> • Operational Availability • Reliability • Maintainability • Compatibility • Logistics and Manpower Supportability • Transportability • Upgradability • Safety and Human factors
QUALITY SERVICE	<ul style="list-style-type: none"> • Ability to support warfighting and combat support systems • Information must be transferred accurately and unambiguously. 	<ul style="list-style-type: none"> • Availability • Delay • Blockage

Table 1c. Summary of CRD requirements and performance attributes

a. Coverage

DOD requirement for wide-band services is 24 hrs a day global coverage that covers all latitudes and longitudes, specifically the six geographic regions as follows:

- CONUS and Americas
- Atlantic-Europe-Africa
- Asian-Indian Ocean
- Pacific
- North Polar (all Longitudes above 65 degrees north latitude)
- South Polar (all longitudes below 65 degrees south latitude)

The driving need is attributed to the shift of global interest and threat environment where conflicts/crises are unpredictable in location, time, intensity and duration which entails globally dispersed land, sea, air and space operations. Today's legacy systems provide coverage to most areas in the first four regions (with limited capacity). However, MILSATCOM has placed very few requirements for the South Polar Region in the past mainly

due to prohibition in-view of international treaties and agreements, none-the-less, that region may receive emphasis if DOD user requirements emerge in the future. On the other hand, the North Pole region, despite the fewer requirements identified in the past than the first four regions, is now of vital importance to US military based on historical and future important military execution of the national security strategy. Some of the unprotected SATCOM requirements at the Polar Regions are primarily but not limited to logistic and scientific support. Other requirements such as Nuclear Attack Submarine operations and "Operation Deep Freeze" Antarctic operations are stipulated in the **classified** Polar SATCOM ORD which are beyond the scope of this research study.

Coverage can be defined, as the ability to dynamically focus required satellite capabilities to where the varieties of users are located across the face of the globe when they need it. This implies that coverage has two attributes, time and geographic (earth surface area). These would in turn determine significant design, cost and performance trades made on spacecraft antenna technology, the number of satellites in a constellation and the constellation's orbital parameter so as to characterize a system's time and geographic coverage.

In-addition, coverage should also provide the ability of the user to move and access at the same time in any combat environment including double canopy/jungle, inside a building, in rain, at sea and while flying, which is directly linked to signal energy available from user terminals to satellite on orbits and vice-versa. For operation under aforesaid conditions without gaps in coverage, parameters such as terminal type, terminal size/weight, operating frequency, weather, terminal's setting up time, desired data rate, desired bit error rate and environmental factors (humidity, salt, sand mud, etc) have to be considered so as to reflect the user's needs. The threshold requirement will be 24 hrs a day combat environment coverage in the first 4 regions with the objective requirement that includes the North and South Polar Regions.

b. Capacity (Throughput)

CRD definition of Capacity is the maximum rate of information transmission and this requirement is driven by an increase in user need for reliable information in response to doctrine and technology. In particular, with the advent of new weapon technology, new reconnaissance systems and surveillance and targeting systems, adequate capacity has to be assured for user when and where needed.

Three performance parameters, such as Data integrity or Bit Error Rate (BER), terminal data rate, and quantity of accesses can measure systems capacity. Firstly, critical to the definition of capacity is the determination of reliable information, which equates to the BER of the products and applications the user terminals will support under all conditions such as in rain or in tropical region. (i.e., Atmospheric effect, rain, smoke and salt particles in the air can cause severe attenuation to radio waves above 10 Ghz thus degrading BER). Acceptable BER is user needs driven which can range from 1×10^{-3} for speech telephony to $<1 \times 10^{-10}$ for computer networks and Global Broadcast Service. The following listed the DOD threshold and objective requirement for Data integrity (BER).

- Threshold at 1×10^{-10} which is the current GBS requirement
- Objective at $<1 \times 10^{-12}$ which reflects user desire for uncorrupted data

Second, the data rate which is the system's maximum throughput to a single user, which is normally advertised by the vendor as what the system is capable of providing to a single standard terminal under ideal conditions. As with BER, acceptable data rate is also user needs driven which can range from <9.6 kbps for low data rate application to greater than 1.544 Mbps to fulfill high data rate requirement (DOD definition of Medium data rate are those between 9.6 Kbps to 1.544 Mbps). Threshold and objective values are estimated at 1.544Mbps (T1) and 3 Mbps respectively based on the ever-increasing user desire and demand due to advent of "capacity draining" software and technology. Note these values are arbitrarily chosen and not grounded by any hard evidence.

Thirdly, quantity of access is the measure of overall systems capacity, which includes:

- The maximum number of access that a vendor can provide for DOD routine underway operations based on the fact that DOD will not be the sole users and will have to directly compete with commercial customer and other interested parties (that includes possibly enemy forces).
- The vendor's ability to accommodate a surge in capacity in fairly small region. However, this is often in direct conflict with a commercial vendor's desire to operate a cost effective full time at or near capacity system and there is little incentive to maintain a robust surge capacity such as holding capacity in reserve to meet wartime requirement. Therefore commercial surge capacity will come at a price (usually monetary cost) to DOD.

As the author has no concrete data in estimating the number of users within DOD and their required capacities, thus no threshold or objective values could be established at this stage of the study. Emerging systems will be scored or ranked based on the vendors' capacity limit and excess capacity available per unit geographical area coverage.

c. Protection

Protection includes Anti-Jam, covertness (LPI/LPD³), nuclear survivability, and resistance to physical destruction. Commercial SATCOM may provide some of these capabilities unintentionally due to a particular system design or configuration, such as the intrinsic LPI/LPD capability of high frequency, narrow beam width Ka band systems, but certain designs may increase the vulnerability to various forms of electronic warfare (EW). Thus, DOD requirements that do not need this set of protection attributes are candidates for

³ *LPI/LPD – Low Probability of Interception and Detection.*

commercial systems. However, the requirement of **confidentiality**, **authenticity** and **integrity** in-order to protect against hostile information operations should not be negated in the selection of commercial systems.

- Confidentiality encompasses data secrecy, traffic secrecy and geo-location secrecy, that is, keeping information from being transmitted to anyone not authorized to receive it, protecting user from traffic analysis and protecting user's physical location. The first aspect might be achieved by employing encryption devices at the user end, however the other two are sticky points for commercial providers in that it may be a primary method for user billing and accurate geo-location to efficiently close the communication link. Despite this problem, DOD users need to remain autonomous and should not have their traffic patterns analyzed and being exploited of geo-location data that can be detrimental regardless of whether the user is trying to remain covert or not. Thus measuring how a vendor intends to protect user confidentiality will be difficult, none-the-less; approach can be to look at the degree of the vendor's controlled access to user address and geo-location database and the procedure of notifying users when inquiries are made about them.
- Authenticity keeps users on either sides of a transmission from being able to forge a message or deny that they had sent or received it. The information has to be delivered exactly as sent with originator and receiver of this information clearly identified. Again measurement of an "authenticity capability" is difficult to quantify and therefore will be subjective on how the vendor is going to address this issue within their system. Some of the elements that should be included in accessing the authenticity of a system are:
 - The protection of billing database that associates a user's SATCOM address with his actual identification.
 - Use of authentication keys
 - Implementation of procedures that prohibit dual use of user IDs.

- Implementation of procedures that notify authorized users that their ID may have been compromised.
- Integrity keeps information from being lost, changed or repeated during transmission. Protection against message modification is closely coupled with confidentiality and authenticity, as the ability to modify a user's transmitted message implies compromise of confidentiality and authenticity. Thus measurement of this attribute is again subjective and should be in line with the other two aspects mentioned.

The three aspects mentioned are directly link to the system design characteristics which are either proprietary or still "on paper" and effectiveness of each is also difficult to measure, However, basic approaches established in the above paragraphs can be adopted once more concrete data is available. None-the-less, assuming the fact that vendors would need to protect themselves from any form of exploitation in damaging the integrity of their network, one can assume that these aspects will be their primary performance measures in designing and establishing their systems.

d. Access and Control

Assured Access is the certainty that the requested amounts of SATCOM services are immediately available and accessible for use when and where they are needed and Control is the ability and mechanisms needed to effectively plan, monitor, operate, manage and manipulate the available SATCOM resources. The evaluation of commercial systems must highlight a system's ability and inability to meet these needs. Clearly full DOD control and total access of a commercial system is not likely, as profits, generated by providing quality service is critically dependent on a corporation's access and control capabilities. Thus, in this perspective, the performance attributes should focus on the capability of commercial SATCOM

systems to provide prioritization,⁴ preemption⁵ and dedicated circuit to DOD with the exclusive ability to maintain access authority and resource control over its own users.

Based on the fact that most of these high cost wide-band SATCOM constellations are internationally funded, the possibility of being denied access and loss of control in time of needs might be unavoidable. Therefore, to mitigate the risk involved in the use of a particular SATCOM, an additional attribute have to be considered, which is the ability or inability to politically and legally influence a SATCOM provider to maintain access and control through all phases of military operation. To certain extent this can be predicted based on the relationship that the owners (i.e., consortium members, major stockholders, associated financial institutions) of the service have with the US military. From this perspective, the author is of the opinion that the threshold would be those who have economic agreements with the US and at-least one controlling partner of the consortium is a US company. The best will be those that have military and economic alliances with the US and have demonstrated to be consistent supporters of US international policy.

e. Interoperability

CRD definition of Interoperability is the ability of systems, units or forces to provide and accept information from other systems, units or forces in an effective joint operation. This encompasses interoperability between ground, air, maritime and Special Operation Forces as well as interoperability between allies and coalition partners and other US government agencies. The performance attributes should focus on interfaces to the Public Switched Telecommunication Network (PSTN), the Defense Information System Network (DISN) and other vendor systems as the basic way to provide the required interoperability.

⁴ Prioritization is the process by which the next available circuit is assigned to the highest priority user in the queue.

⁵ Preemption is the capability of a high priority user to interrupt a cell and seize the circuit.

f. Flexibility

Flexibility is defined as the ability to support a dynamic range of military operations, missions and environment. This can be justified based on the need to prosecute military operation across a wide spectrum of conflict, the need to accommodate evolving doctrine, requirements, threats, technologies and the system should be reliable, easy to use and safe to operate in the intended environment. As indicated in the discussion of "Access and Control", DOD will probably not have any form of control on the SATCOM systems, thus from this perspective, the measure of the performance attributes of flexibility will be narrowed down to just the operation and physical terminal at the user end. (With assumption that the rest are in proper operation) The performance attributes to the flexibility of a commercial SATCOM terminals are listed as follows:

- Operational Availability – a measure of the degree to which an item is in operable and committable state at the start of a mission when the mission is called for at a random time. However, due to the immature state of emerging systems involved, this attribute will probably have to be obtained via simulation that reflect intended operational environment and timelines as discussed in the thesis written by Darin L. Powers [Ref. 7].
- Reliability – probability of failure-free performance under stated conditions, again similar to the Operation Availability, simulation has to be done and output should quantify reliability in terms of projected mean time between operational availability failure.
- Maintainability – defined as the ability of an item to be retained in or restored to specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. Accurate evaluation of maintainability should include hands-on repair by qualified personnel, however, again due the immature state of most emerging

system, this approach might not be possible and the alternative is most probably based on vendor's written description of projected maintenance concepts and maintainer skill levels. Things to look out for include; level of effort and training require to perform operator level maintenance, ability of built-in test to isolate fault to line replaceable unit with no additional test equipment and the acceptable duration of routine maintenance so as not to impede operational availability.

- Compatibility – ability of two or more items or components of equipment or material to exist or function in the same system or environment without mutual interference such as Electro-magnetic interference due to the multitude of communication assets employed within relatively confined area. Ideally vendor's earth terminal should not force users to modify war-fighting tactics.
- Logistics supportability – As military use of earth terminal is analogous to the civilian market terminal, it is conceivable that support service could be procured with the purchase (or lease) of a large number of terminals. Against this attribute, the assessment of possible candidates could be based on the contractual arrangement that can be made in terms of what level of logistics supportability will be provided. Possible agreement could be that the contractor repair and transport the repaired parts or re-conditioned (or new) items to a rear area logistics support area within an agreeable time frame just like the military maintenance float concept.
- Transportability – The user terminal must be lightweight and support a number of configurations to include shipboard, land-mobile, airborne and possibly man-portable. General survey shows that most emerging systems are intended for "Internet on the Move", thus inherently should be transportable unless proved otherwise.
- Upgradability – Assessment should be based on whether the candidate system is able to facilitate rapid and orderly enhancements and upgrades to operational capabilities and features. The best bet will be a system design that is based on open system architecture.

- Manpower Supportability – System selected should not create new occupational specialties or increase in manpower requirement.
- Safety and Human factors – System selected should be safe and easy to use in the intended combat environment. Given the commercial nature of the product it is unlikely to be hazardous and documentation should be well written and easily updated so that user can operate with minimum training.

Due to the logistical nature of these attributes, some of them will require contractual negotiations, some require simulation that involved substantial data and others can be considered as “must have” due to its commercial nature. The author thus assumes all systems under consideration for initial screening of potential candidates will achieve DOD threshold requirement. However, these attributes should not be negated in further analysis of any particular system.

g. Quality of Service

‘Quality of Service’ reflects a system’s ability to adequately conduct required information transfer in a timely and accurate manner. To access an emerging wide-band system, the following performance attributes could be used.

- Availability – This measure should be provided by the vendor and reflects his contractual responsibilities to provide an assured probability of access despite of system congestion or during periods of high network traffic (within geographic and time coverage of the system). This could be achieved based on the priority user scheme

offered by the vendor. DOD objective and threshold should be greater than 99.9%⁶ and 97% [Ref.16] probability of access for high and low priority user respectively.

- Delay and Blockage – Similar to Availability, these measures should be provided by vendor and reflect his contractual responsibilities to provide timely delivery of information regardless of system congestion or during high network traffic (assuming user has access). Two quantifying values that could be used to measure delay and blockage are 'Probability of no delay' and 'Probability of no blockage'. Author is of the opinion that the threshold and objective values would be greater than 97% and 99.9% [ref. 16] for high and low priority user respectively.

2. Commercial Viability

As indicated in the introductory session of this chapter, some of the wide-band systems are still in the proposal stage and those in developmental stage are only expected to start operation at 2000 to late 2000 time frame. Furthermore, the more than ten U.S.-licensed companies participating in this highly competitive field are scrambling to obtain equity financing from a limited pool of available capital. It is clear that not all will attain operation. Therefore, a selection of candidates for DOD consideration should consider their commercial viability. Some of the key factors are:

a. Regulatory approval

Obtaining satellite spectrum is a multiyear process that can involve different criteria on the parts of the FCC⁷ and ITU.⁸ Satellite systems must be registered with the ITU to reserve orbital slots and operating frequencies. National licenses are required to launch and

⁶ This estimated value is based on typical examples from "Wireless Communications", Theodore S. Rappaport, Prentice Hall, 1996.

⁷ Federal Communication Commission.

⁸ International Telecommunication Union.

operate satellite systems (In U.S. this is governed by FCC). However, spectrum approval does not spell the end of the process. Approvals do not necessarily mean a provider gets first dibs on the spectrum, so satellite providers may end up with secondary rights to frequencies already approved for another provider (adding technical complexities to service provisioning). Following international approvals, global providers must acquire site operation licenses, PSTN⁹ connection approvals and landing rights¹⁰ to allow operation of the satellite in that particular country. Note that each licensing process is often preceded by lengthy negotiation and coordination among competing interest and systems to resolve issues such as intersystem interference, spectrum sharing, equal access to the spectrum for all competitors, etc. Threshold of selection will be those who have received FCC system licenses and reserved orbital slots and operating frequency from ITU and best will be those that have obtained all regulatory approval, licenses and landing rights.

b. Funding and Corporate Backing

Most satellite systems are billion-dollar ventures with the bulk of funding required up-front without any guarantee of success. To survive, companies need deep pockets or deeper alliances and must demonstrate commitment by pledging substantial equity and investing venture capital in establishing the enterprise and initiating system development. However due to the fluidity nature and the multiple influencing factors that might change the perspective in any given time. The author is of the opinion that a team of experience market and financial analysts need to be engaged for accurate assessment. However, estimated cost and the amount of capital investment that has been committed by each backer and owner of the respective systems will be presented in subsequent chapters.

⁹ *Public Switch Telephone Network connection approvals: which may provide critical links to other communication systems.*

¹⁰ *refers to the placement of terminals on host nation soil.*

c. Market Acceptance and Access

Consumer acceptance of the new service is crucial and most of them are analogous to DOD requirement, thus commercial system will be ranked and scored based on how attractive they can provide the following to the user:

- Are the service rates affordable?
- Are the terminals convenient (size, setup, operation) and affordable?
- Has an adequate distribution and customer service system been established?

d. Technical Feasibility

Next-generation systems rely on new technology, such as inter-satellite links, that are not yet fully tested. New systems, like Broadband LEOs¹¹ may also add new problems, such as jitter.¹² The inherent problem of GEOs,¹³ latency¹⁴ also has to be resolved in-order to accommodate broadband data. Even billing issues can be huge, since these systems will need to pioneer new global invoicing processes. Thus systems with proven technology and straight forward architecture pose less technical and schedule risk and are likely to cost less. A more detailed discussion will be presented in the Chapter VI.

C. SUMMARY

In summary, as some of the system are still in “paper concept” or still at the development stage, thus evaluation of some of the performance attributes and factors are beyond the scope of this thesis. Therefore, the author will perform an initial screening based on resources that are available. A cross-reference matrix listing each requirement by attributes and factors that will

¹¹ LEO – Low Earth Orbit Satellite at 400 to 1000 miles from earth’s surface.

¹² Jitter – The variable time delay for data transfer between 1 earth terminal to LEO satellite and another earth terminal to the same LEO satellite.

¹³ GEO – Geo-stationary Orbit Satellites maintain an orbit 22,300 miles from earth surface.

¹⁴ Latency – The long time delay (~ 0.24 sec) for data to get from GEO satellite to earth terminal and vice versa.

be considered in accessing the emerging system will be generated and recommendation of the "best value" candidate system will be based on appropriate weighting factor applied to each requirement. The author is of the opinion that factors correspond to 'risk involved' should be giving a higher weighting factor than 'performance' and 'affordability' and factor that corresponds to 'supportability' should be of lower weightage than the rest. In-addition system that does not meet requirement threshold (minimum acceptable performance) or doesn't equipped with the necessary capability will be determined of no value and will not be considered for further evaluation in this research study. Note these analogies are solely the author's point of view at the date of the research, necessary adjustment has be made in future analysis when more concrete information and prioritization of the requirements is established. The format of this cross-reference matrix with 5 possible wide-band satellite systems is displayed in Table 2.

Requirements	TELEDESIC		ASTROLINK		CYBERSTAR		SPACEWAY		SKYBRIDGE	
	Capability	Score	Capability	Score	Capability	Score	Capability	Score	Capability	Score
Access and control										
Preemption										
Prioritization										
Dedicated Circuit										
Relation with US										
Coverage										
Interoperability										
PSTN interface										
DISN interface										
Universal Terminal										
Regulatory Approval										
Market Acceptance										
Service rate										
Terminal cost										
Quality of Service										
Capacity										
Data integrity (BER)										
Data rate										
Quantity of access										
Technical Feasibility										
Protection*										
Flexibility*										
Funding and Corporate Backing*										

* Not assess

Table 2. Cross reference matrix for accessing emerging Wide band satellite systems

III. OVERVIEW OF CURRENT DOD COMMUNICATION SATELLITE CONSTELLATION

A. CURRENT ARCHITECTURE

The current DOD's space communication architecture consists of numerous systems, which are divided into categories, based upon the type of services they offer as shown in the following illustration.

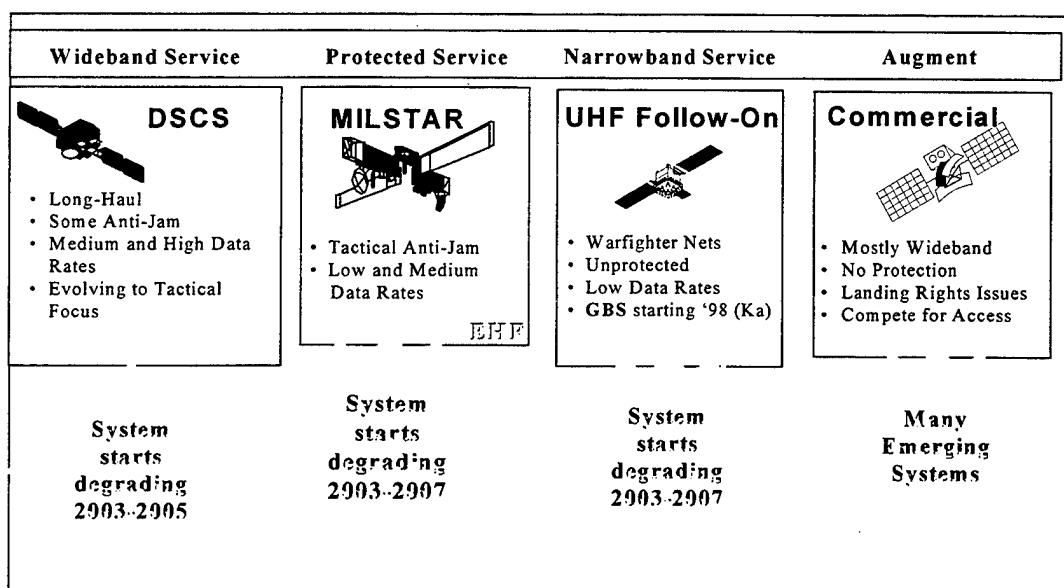


Figure 2. Current MILSATCOM Architecture From Ref. [3]

There are four segments in the military satellite communications (MILSATCOM¹⁵) architecture. First, Ultra High Frequency (UHF) satellites are the workhorses for tactical ground, sea, and air forces. Second, the Super High Frequency (SHF) Defense Satellite Communications System (DSCS), first deployed in the 1970s, supports long-distance communications requirements of military forces and design to satisfy the majority of DOD's

¹⁵ MILSATCOM encompasses all types of SATCOM systems and services used by DOD – both DOD owned and operated SATCOM systems and DOD's use of commercial SATCOM services.

medium and low data-rate communication requirements. Milstar (Extremely High Frequency), the third segment of the MILSATCOM architecture provide a worldwide, secure, jam-resistant communication capability to US civilian and military leaders for command and control of military forces. The fourth segment consists of commercial communications satellites such as INMARSAT, INTELSAT etc., which are used to support DOD's MILSATCOM capabilities where jamming protection is not required. In addition to US MILSATCOM satellites, with prior permission, the US military can use certain other MILSATCOM systems such as Skynet from Great Britain and constellation established by NATO.

The frequencies most often used are the Ultra-High Frequency (UHF), Super High Frequency (SHF), and Extremely High Frequency (EHF). There are different models of satellites, which are tuned to operate in one or more of the above frequency bands. The unique attributes of each system lend themselves to specific missions or form of communications. The purpose of this chapter is to provide a quick summary of current in-orbit, DOD owned and leased system illustrating their capabilities, service offer, anticipated mission lifetime and the most probable replenishment architecture in addressing the needs in the 2004 to 2015 timeframe.

1. The (SHF) Defense Satellite Communications System (DSCS)

First deployed in the 1970s, the system supports long-distance communications requirements of military forces that cannot be met by ground-based communications systems. The DSCS system satisfies the majority of DOD's medium and low data-rate communication requirements that is supporting data rates from 75 bps to 1.544 Mbps. The current network composed of DSCS II and III satellites, where DSCS II is the older models and most have them been phased out due to age or failure. The current DSCS III constellation consists of six satellites in geo-stationary orbit. Each satellite is a three-axis stabilized vehicle using the SHF band. Six channels and six transponders (one channel per transponder) are provided for both protected and unprotected communications signals. Antenna coverage is provided through four earth coverage horns (two receive, two transmit), one gimbaled dish transmit antenna, two 19-

element multi-beam transmit antennas, and one 61-element multi-beam receive antenna, which can be adjusted in both phase and amplitude.

DSCS III is a tri-service program managed by DISA, for which the Army is the Primary Inventory Control Agency (PICA) and the Air Force is the Secondary Inventory Control Agency (SICA). The DSCS satellite constellation is used by the Air Force, Army, Navy, Marine Corps, the National Command Authority (NCA), the World Wide Military Command and Control System (WWMCCS), the Ground Mobile Forces (GMF), the White House Communications Agency (WHCA), and the Diplomatic Telecommunications Service (DTS). Their main functions are to provide secure strategic/tactical voice and data transmission, national security command and control which include high priority communications such as the exchange of wartime information between defense officials and battlefield commanders. The military also uses Defense Satellite Communications Systems to transmit space operations and early warning data to various systems and users.

Latest expansion to the DSCS constellation will be the DSCS III SLEP (System Life Enhancement Program) where the first satellite to be launched in July 1999. A summary of this system is as shown in the following table.

Defense Satellite Communications System (DSCS)			
Control/Management	Joint Staff, SPACECOM, DISA	Operational status	Operational; continuing satellite replenishment
Operation & Maintenance	DISA, service O&M agencies	Network Availability	Available thru fixed earth/mobile tactical terminals, some aircraft and Navy hips
Purpose:	Long-haul military transmission system	Throughput:	75 bps to 1.544 Mbps with special modification
User(s):	DOD/select non-DOD agencies	Security/COMSEC:	Bulk encryption, DES privacy to TS/SCI
Area Coverage:	Worldwide, except for some extreme N/S latitudes	Protection:	Partially AJ protected (DSCS III); both fixed earth terminals and mobile tactical equipment
Modes of services:	Secure Voice, record, data, and video conferencing	Mobility:	Fixed, semi-mobile, and mobile earth terminals
Major Contractors:	DSCS III – Martin Marietta Astro Space		

Table 3. Summary of DSCS from [Ref. 4]

2. EHF Military Strategic Tactical And Relay (MILSTAR)

This joint military services program call MILSTAR was conceived to develop a survivable, worldwide satellite communications network for strategic and tactical users. MILSTAR is designed to support emergency action message (EAM) dissemination; the command, control, coordination, and status reporting requirements of the unified and specified commands, and tactical force communication.

The Milstar satellite system, which has been under development since the early 1980s to provide survivable and jam resistant Extremely High Frequency (EHF) communications to strategic and tactical users has experienced major cost and technical problems. This program also experienced a major reorientation in 1990, away from support of strategic nuclear war-fighting with the Soviet Union, towards support of conventional forces in the Third World.

The current operational Milstar satellite constellation composes of two block 1 satellites positioned around the Earth in geo-synchronous orbits plus a polar adjunct system. Each mid-

latitude satellite will weigh approximately 10,000 pounds and have a design life of 10 years. The first Milstar satellite was launched Feb 7, 1994 aboard a Titan IV expendable launch vehicle. The second low data rate satellite was launched in 1995. Beginning with the third launch in 1999 (Block 2), the satellites will greatly increased capacity because of an additional medium data rate payload. A combined low and medium data rate capability will be introduced on subsequent satellites; up to three more Milstar (block 2) will be launched through approximately 2002.

The MILSTAR communications payload consists of LDR communications (voice, data, Teletype, and facsimile) at 75 bps to 2400 bps (all satellites). MDR communications (voice, data, Teletype, and facsimile) at 4.8 kbps to 1.544 Mbps (satellites 3 through 6 only). The MILSTAR LDR EHF payload has 192 channels with rates between 75 and 2400 bps. Block 2 spacecraft will carry the LDR in addition to a MDR payload. The MDR will provide rates of 4800 bps to 1.544 Mbps per channel. The MDR payload also includes two nulling spot antennas that can identify and pinpoint the location of a jammer and electronically isolate its signal, allowing MILSTAR users to operate normally and at full capacity with no loss in signal quality or speed.

Several design features distinguish Milstar from previous military and commercial satellite communication systems. First, the Milstar satellite serves as a smart switchboard in space, allowing users to establish critical communication networks on the fly, making Milstar extremely flexible and responsive to the needs of the tactical warfighters. Secondly, the Milstar system uses a satellite-to-satellite crosslink to provide worldwide connectivity without the use of vulnerable and expensive ground relay stations. Finally, the unique characteristics of the Milstar Extremely High Frequency (EHF) waveform prevent adversaries from using DOD communication signals to determine the location of our forces (Low Probability of Intercept), and allow Milstar to overcome all known jamming threats (Anti-Jam).

Key goals of Milstar are to provide interoperable, protected (anti-jam) and survivable (anti-scintillation) communication service that is unique to a military system so as to maintain

freedom of action during the deployment, maneuver, and engagement phases of military operations. A summary of this system is as shown in the following table.

MILSTAR			
Control/ Management	USSPACECOM, AFSPC	Operational & Maintenance	AFSPC, commercial contractor (such as, Lockheed Martin)
Purpose:	Jam-resistance C2	Throughput:	1.2 kbps to 1.544 Mbps
User(s):	DOD, CINCs, services	Security/ COMSEC:	Up to TS/SCI
Area Coverage:	65S to 65 N + Polar region	Protection:	Electromagnetic Pulse hardening; electronic AJ feature
Modes of services:	Voice, data, video	Mobility:	Strategic and mobile tactical user
Major Contractors:	Lockheed Martin, Hughes Space System, TRW Space and Missile Group		

Table 4. Summary of Milstar from [Ref. 4]

3. Ultra High Frequency (UHF) satellites

There are three types of UHF satellites (FLTSAT, UHF Follow-on, and Satellite Data System [SDS]). The first two are in geo-synchronous orbits providing coverage of the earth surface between 70 N and 70 S. These fall into groups that are primarily for narrow band services supporting tactical mobile forces. The two satellites of the Satellite Data System (SDS) support near-real time communications between low altitude photographic intelligence satellites and ground control stations, using highly elliptical semi-synchronous Molniya-type orbits, optimized for coverage of the North Polar Region. SDS F-5 and F-5A, launched in 1983 and 1984 respectively, are probably still in service.

The FLTSAT and UHF Follow-On form the FLTSATCOM constellation supporting tactical mobile forces. Current inventory includes FLTSAT 1, 4, 7 and 8 which have exceeded their design life and are gradually being replaced by UHF Follow-on satellites which will consist of eight satellites and one on-orbit spare. UHF satellites F2 through F8 are in orbit and are fully operational. UHF F1 is functional, but in an unusable orbit due to a launch vehicle

failure. UHF F9 was launched on 20 Oct 98 from Cape Canaveral Air Station aboard a Lockheed Martin Atlas IIA rocket. This satellite is the ninth in the series, as well as the second of three with a Global Broadcast Service (GBS) payload (F8 is first in the series). When the third GBS spacecraft (F10) is launched next year, the Department of Defense will have near-global, high-speed, wide-band coverage for warfighters on land, at sea and in the air (The GBS system will be discussed in the next section). In-addition, EHF packages are also placed on satellites F4 to F9 and later F10, designed to receive uplink signals in the EHF band and downlink them in SHF, UHF or both bands, a process known as crossbanding. The UFO EHF functions are a subset of Milstar capabilities.

In Summary, UHF systems support tens of thousands of stationary and mobile users ashore and afloat providing links between naval aircrafts, ships, submarines and ground stations, and between strategic air headquarters and the National Command Authority (NCA) network.

UHF Follow-on (UHF portion)			
Control/Management	Joint Staff, SPACECOM, Navy, DISA	Operation & Maintenance	SPACECOM
Purpose:	Long Haul, single channel, satellite transmission service	Throughput:	Channel dependent: 5 or 25 KHz
User(s):	DOD wide, government agencies	Security/COMSEC:	Up to TS/SCI dependent on COMSEC and keymat
Area Coverage:	65N to 65S	Protection:	Vulnerable to jamming and interference
Modes of services:	Voice, record and data	Mobility:	Fixed and mobile facilities
Major Contractor:	Hughes Space and Communication Company		

Table 5. Summary of UHF Follow-on from [Ref. 4]

4. Global Broadcast Service (GBS) Program

The GBS system is a space based, high data rate communications link for the asymmetric flow of information such as imagery, intelligence, missile warning, weather, recorded message traffic, joint/service-unique news, education, training, live video and MWR programming from the United States or rear echelon locations to deployed forces. The GBS system is designed for "smart pushing" of high volume of intelligence, weather and other information to widely dispersed, low cost receive terminals. The system also includes a capability for the users to request or "pull" specific pieces of information. These requests will be processed by an information management center, where they will be prioritized, processed and then scheduled for transmission.

The Global Broadcast System Program was approved in September 95, so as to capitalize on the popular commercial direct broadcast satellite technology to provide critical information to the nation. This was designated as a joint program on 27 March 1996, by direction of the Under Secretary of Defense for Acquisition and Technology (USD(A&T)). A number of decisions were embedded in the formal program designation and have also been approved by the Congress. These include the current phased approach for providing satellite broadcast payload assets over time.

A major decision was made to place a limited capability GBS payload onboard the last three UHF Follow-On (UFO) spacecraft (UFO 8, 9, and 10). Due to the decision regarding the UHF Follow-On spacecraft GBS capability, the space segment assets will have at least three distinct phases of fielded capability. The three phases are described below:

Phase 1 (FY96 - FY98): Limited leased commercial satellite services operating at Ku-band for Concept of Operations development, demonstrations, and limited operational support.

Phase 2 (FY98 - FY06+): Payload packages hosted on UHF Follow-On satellites 8, 9, and 10 with the downlink broadcast operating at 20.2-21.2 GHz (Ka-band). As only three UHF

Follow-On satellites will be equipped with the GBS Ka-band payloads, the continued lease of commercial satellite services at Ku-band will be required to augment UFO GBS where coverage gaps exist and may be required to complement the UFO GBS limited number and size of downlink beams.

Phase 3 (FY06+): The objective of phase 3 is to provide increased capacity, worldwide coverage, and the capability to broadcast near continuous or time critical information to broadly dispersed users. The specific solution for the GBS long-term capability will be developed in accordance with the DOD MILSATCOM Architecture as maintained by the DOD Space Architect.

5. Leased Commercial Satellite Services

The fourth segment of MILSATCOM architecture is the leased commercial satellite services, which has proved to be valuable in the execution of military operation such as Operational Desert Storm and Desert Shield in the early 90s. Applications include but are not limited to direct communications support to commanders using INMARSAT and the connecting of deployed U.S. Central Command headquarters in Saudi Arabia to critical computer and communication systems at permanent headquarters facilities in Florida using INTELSAT. Since then (the operation in Persian Gulf), DOD usage of these two constellations have grown and they have become an integrated part of DOD communication infrastructure.

a. INMARSAT

INMARSAT was established in 1979 to serve the maritime industry by developing satellite communication for ship management and distress and safety applications. An intergovernmental structure presently with 85 countries, it has since expanded into land, mobile and aeronautical communications. When INMARSAT began service in 1982, its remit was to provide communication for commercial, distress and safety applications for ships at sea. The INMARSAT charter prohibits use of the system for military purposes during wartime, but under current legal interpretations this does not forbid military use during humanitarian or

peacekeeping operations authorized by the United Nations. Thus INMARSAT was heavily employed during Operations JUST CAUSE, DESERT STORM and RESTORE HOPE. Connectivity is provided through commercial phone systems to fixed sites or through portable INMARSAT terminals. Since then programs such as GAPFILLER involved in the leasing of some channels on selected INMARSAT satellites in support of the U.S. Navy has been initiated. Over the past decade, military use has been increased steadily as an alternative to military satellite systems to provide voice, data videoconferencing and slow-scan video services up to 56 Kbps with its base of nine Geo-stationary satellites.

INMARSAT's name is an acronym of its original full title, the International Maritime Satellite Organization, and, while it has branched out into other, non-maritime markets and changed its name to the International Mobile Satellite Organization, the acronym has remained. Inmarsat grew out of an initiative of the then International Maritime Consultative Organization, now the International Maritime Organization (IMO). During 1979, mobile satellite communication was an unexplored technology. So it was decided that Inmarsat should be a joint co-operative venture of governments, with their signatories nominee organizations, in most cases the country's post and telecommunications provider (PTT) contributed the capital and bore the high risk involved.

Two decades after it was established, INMARSAT remains an intergovernmental "treaty" organization, with its world headquarters in London. However, in September 1998, Inmarsat's Assembly of Member governments reached an agreement that Inmarsat will become a commercial company on April 1, 1999. Therefore INMARSAT's corporate structure will change from that of an intergovernmental organization into a form more suitable to conduct a successful commercial business in today's competitive environment. The new structure will comprise the commercial company, which will seek an initial public offering within approximately two years of formation and a small intergovernmental secretariat empowered to ensure that INMARSAT continues to meet its public service obligations including those of the Global Maritime Distress and Safety System (GMDSS). The risks to U.S. military due to this restructuring effort will be raised in-view of its 'new business'

outlook, however should not be too far off from those of emerging commercial systems (to be discussed later).

INMARSAT			
Purpose:	Global voice, data, telecommunications	Throughput:	Voice frequency data up to 9.6 Kbps, high speed data up to 56 Kbps
User(s):	International/ Government agencies, vessel/aircraft operators, corporations	Security/ COMSEC:	User-provided
Area Coverage:	±65 maritime, most land areas	Protection:	None
Modes of services:	Voice, FAX, video and data	Mobility:	Fixed and mobile facilities
Control/ Management organizations	IMSO; U.S. carrier: COMSAT ¹⁶ corporations, national companies and PTT		

Table 6. Summary of INMARSAT after [Ref. 4]

b. INTELSAT

INTELSAT is the acronym for the International Telecommunication Satellites and is also the name for the international consortium formed in 1964 which is made up of communication agencies from each of the participating countries. INTELSAT is composed of 143 members from different nations and since 1965 has provided international satellite communications services linking billions of people throughout the world on a commercial basis. Its prime objective is the provision, on a commercial basis, of the space segment required for international public telecommunications services of high quality and reliability, made available on a non-discriminatory basis to all areas of the world.

¹⁶ COMSAT Corporation is one of the commercial entities formed by the U.S. government as a signatory nominee organization to represent U.S. interests and provide satellites services via INMARSAT and INTELSAT.

INTELSAT's activities are governed by two separate but interrelated agreements. The first, the INTELSAT Agreement, was completed by the members, or "Parties," and sets forth the prime objective of the organization as well as its structure, rules, and procedures. The second, the INTELSAT Operating Agreement, sets forth the rights and obligations of INTELSAT Signatories and investors. INTELSAT's principal governing body, the Assembly of Parties, meets periodically to consider issues of general policy and long-term objectives of special interest to governments. INTELSAT's operations are governed by its Meeting of Signatories (the investors in the INTELSAT system) and managed by its Board of Governors, which has principal responsibility for the design, development, operation and maintenance of the INTELSAT system. COMSAT (now Lockheed Martin since the merger of these two companies in sept 98) represents the U.S. in the Meeting of Signatories and has always been a leading member of the Board of Governors.

Signatories are designated by the members' governments and include many national telecommunications agencies and companies with government ownership. Under the Operating Agreement, Signatories are responsible for financing INTELSAT. Each Signatory owns a share in the Organization and contributes capital in proportion to its use of the satellite system. Capital contributions support INTELSAT's operations, as well as the direct and indirect costs of designing, developing, and operating the system. Signatories receive a return on capital based on the success of INTELSAT operations. However, due to the recent effort in privatizing INTELSAT, these agreements might change, none-the-less, U.S. employment of this constellation for military purposes (since the operation in Persian Gulf) will still continue and is expected to escalate in-view of its recent expansion and upgrading to accommodate broadband services. (Military usage is governed by the same restriction as INMARSAT).

INTELSAT's satellites permit over 170 member and non-member nations alike an opportunity to reap the economic, technical, operational and political benefits of global interconnection. The organization's primary focus is the provision of international "fixed" (e.g.,

telephone and broadcast) public telecommunications services using its current 19¹⁷ Geostationary satellites. INTELSAT is also the first provider of television transmission links between continents. Now, INTELSAT has been extended to encompass not just voice and video services but the new Internet and multimedia applications that are becoming increasingly essential for businesses, individuals and military.

INTELSAT's first duplex 45 Mbps Internet backbone links was implemented over the Pacific between North America and Malaysia. Subsequently, the first hybrid satellite/fiber asymmetric link was implemented for Internet traffic via INTELSAT. This configuration comprises a 45 Mbps carrier on the INTELSAT 802 satellite in the Pacific Ocean region, combined with a trans-Pacific cable connection for the return path. Similar services will soon be carried on Atlantic Ocean region spacecraft. Four 34 Mbps carriers are operating in symmetric links providing extensive coverage of the North and South America. Five¹⁸ more launches of its INTELSAT IX series satellites are also expected in the 1999 to 2001 timeframe to meet the demands then.

A summary of INTELSAT is illustrated in Table 7. Given that the INTELSAT is a fully operational constellation and is expected or already being integrated as part of DOD broadband infrastructure. INTELSAT could serve as an important yardstick in the selection of emerging wide-band systems. Note the parameters presented in Table 7 will be further elaborated in Chapter IV.

INTELSAT	
Key Investors	143 nations
Key U.S. investor	COMSAT Corporation (part of Lockheed Martin since sept 98)
Market Strategy	Direct and whole sale to ISPs, telecommunication companies, broadcast network, multinational corporations
Estimated Customer Cost	Competitive with terrestrial
Cost of satellite	200 million each
Number of satellites in service	19 GEOs fully operational
Expected size of constellation	24 GEOs

¹⁷ The current 19 in-orbit satellites include the 5 satellites that transferred to New Skies Satellites N.V. in sept 98, New Skies is a independent private company spin off from INTELSAT.

¹⁸ One of the Five will be transferred to New Skies.

Operating frequency	C and Ku Band
Protocols/Interfaces supported	Ethernet, LAN, IP, Frame relay and ISDN etc.,
Bentpipe/ On board processing	Bent Pipe with no on board processing
Estimated aggregate bandwidth	Greater than 50 Gbps
Customer Bandwidth Options	Symmetrical : 64 Kbps, 1.54Mbps , 1 Gbps Asymmetrical : 64 Kbps to 155 Mbps
Antenna Diameter and estimated price	60 cm to 32 m: \$1000 to \$1million; stationary and mobile
Round trip latency	500 msec
Expected business use	Voice, Internet, TV broadcast
FCC/ITU approvals	100%
Security and Comsec	User provided
Protection	None
National approval signed	143 nations

Table 7. Summary of INTELSAT after [Ref. 9 & 10]

B. Future MILSATCOM Architecture

Current DoD-owned MILSATCOM systems are projected to continue to provide service till 2010 based on mean satellites lifetime as depicted in Figure 2. Additionally, with the relocation of likely conflict as in the Cold War era to a Global and diverse arena and with the increasing information appetite of technologically advanced weapons, the reliance of US deployed forces on robust space based communications has risen exponentially as shown in Figure 3.

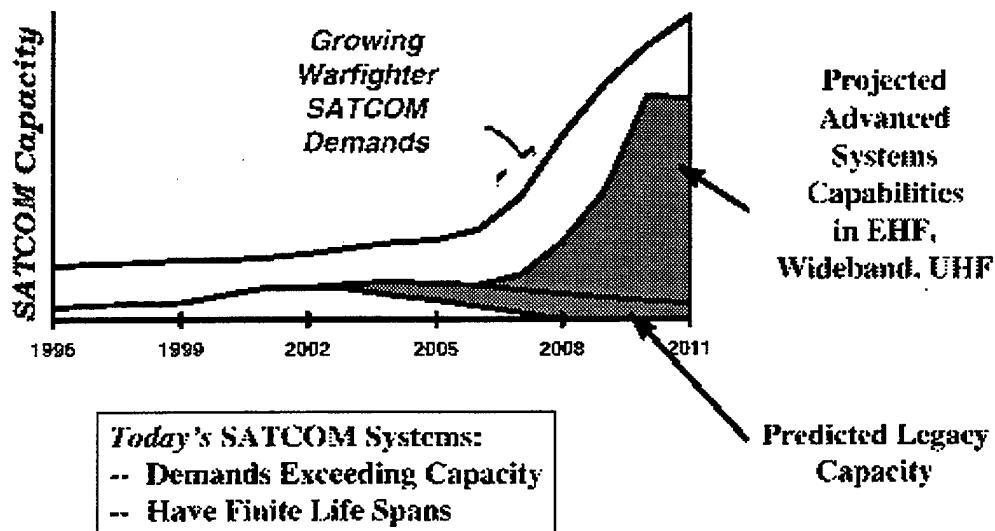


Figure 3. Projected SATCOM capacity from [Ref. 5]

The Joint Requirements Oversight Council (JROC) recently approved the course of action developed by the senior warfighters from the Unified Commands as shown in Figure 4.

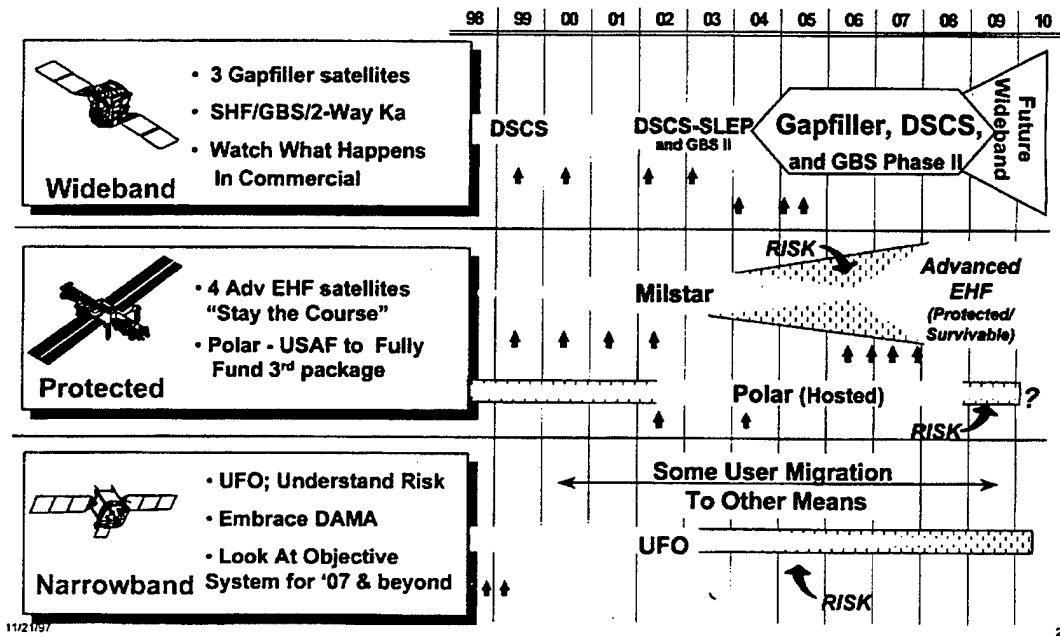


Figure 4. MILSATCOM Course of Action from [Ref. 6]

It is clear that DOD will continue to invest heavily in precision warfighting and combat support systems that rely on space-based systems for their information. In 2004 and 2005, three new DOD-owned, high capacity, commercial-like wide-band satellites, focused on supporting deployed war-fighters will be deployed. These satellites will supplement the remaining Defense Satellite Communications System (DSCS) constellation and Global Broadcast System (GBS) capability on the Ultra High Frequency Follow-On (UFO) satellites. This "gapfiller" satellite is to give DOD an increase in tactical wide-band capability and allows DOD time to assess the performance and cost of emerging commercial services.

The capability to provide protected (antijam) and survivable (antiscintillation) communication service is unique to a military system. There is no commercially available

equivalent. The transition strategy from today's MILSTAR systems to the future EHF systems is to continue to field a processed and cross-linked EHF system, improving capability incrementally. MILSTAR will stay the course with the projected requirements, following it with a new system launching in 2006 and 2007.

In order to fulfill the military need for protected service above 65N, the EHF Polar adjunct system is already in-orbit and a second polar package will be launched in FY02 to provide service 24hrs a day. Planning and costing for polar package number 3 to replenish polar number 1 is underway. Beyond 2010, the LPI/LPD polar service could continue to be provided by a HEO EHF payload, or by the future UHF system (if that system is in an orbit providing polar coverage/access).

The capability to provide mobile-netted communication service may be unique to a military system. There is currently no commercial equivalent; however, the planned commercial systems that are designed to provide global cellular telephone systems may, in the future, provide service equivalent to mobile netted MILSATCOM. In the coming decade, DOD will fly out UFO and the Navy will examine a successor to UFO to provide netted mobile and hand-held voice, paging, and LDR broadcast service with launches planned in about 2007.

The future DOD MILSATCOM architecture is envisaged as in Figure 5, and the basic approach is to maintain control of critical and protected assets while leveraging commercial capabilities to free up critical MILSATCOM bandwidth for increased information flow that is critical and require survivability.

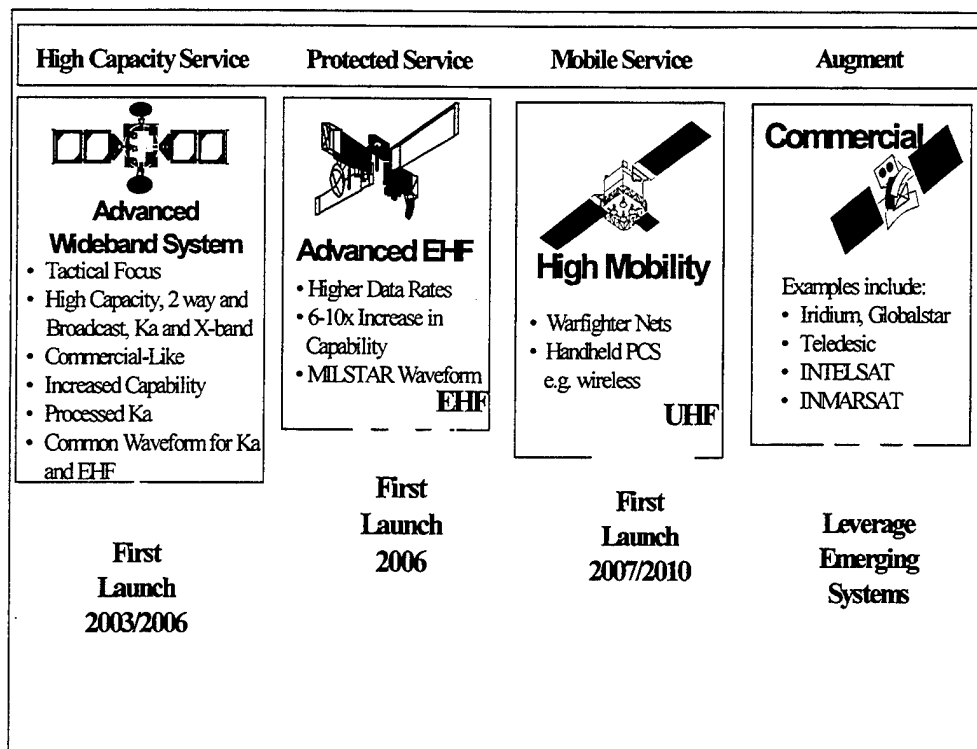


Figure 5. Future MILSATCOM Architecture from [Ref. 3]

IV. COMMERCIAL WIDE-BAND SATELLITE COMMUNICATION SYSTEM

A. INTRODUCTION

Conservative estimates [Ref. 10] suggest that some 500 broadband satellites will be available in about 10 years so as to meet the demand required by the projected 150 million households using the Internet which include high-quality text, voice, data and video communication services throughout the world.

In early 1997, the FCC has granted orbital locations and Ka-band (20-30 Ghz) as well as Ku band licenses to more than 10 U.S. license companies and all aim to bring information into the home and office at a speed of up to 155 Mbps (down link) and 9 Mbps (up link). Five efforts alone--Lockheed Martin's Astrolink, Hughes' Spaceway, Craig McCaw and Bill Gates' Teledesic, Loral's Cyberstar and Alcatel's Skybridge -- plan to launch close to 370 satellites at a cost in excess of \$24 billion. Together these constellations call for aggregate bandwidth of about 3 terabits per second, or the equivalent of about 2 million T1 lines.

B. OVERVIEW OF COMMERCIAL SYSTEM

To exploit these upcoming capabilities to satisfy military requirements, an overall understanding of current status of commercial wide-band SATCOM system is essential. In the author's opinion, it is best to start with a comparison of the different qualities and capabilities of these satellites and the challenges faced by them. (Note some of the factors have been discussed in Chapter II).

1. Satellite orbits

GEO (geostationary earth orbit): GEO satellites orbit at about 36,000 kilometers/22,000 miles (the balance point for earth and sun gravity) at a speed that matches that of the earth's rotation, thus the satellite appear to be stationary in its relationship to earth. GEOs require considerable fuel and critical maneuvering to achieve this orbit. Because GEOs orbit higher,

fewer (about 8 satellites) are needed to cover the globe from approximately 72N to 72S latitude but more power is needed for communications.

MEO (medium-earth orbit): MEO satellites typically orbit at 6,250 miles to 12,500 miles. LEO (low-earth orbit): LEO satellites orbit between 500 kilometers and 2,000 kilometers at much higher rates of speed than GEOs. LEO constellations, consisting of as many as 48 satellites, must be fully launched before service can be provided. Both of them experience less latency than GEOs, but require more satellites in a constellation, thus higher cost. For example, each of Teledesic's 288 satellites will cost in the realm of \$20 million and that's \$5.76 billion just in satellites. This does not include launch fees or insurance. Cost is only one issue. There is also a need to find someone and somewhere to launch these satellites. Teledesic has set an 18-month to two-year launch window to get its 288 satellites airborne. To make it happen, a huge jump in launch capacity is necessary. Once the LEO satellites are in orbit, there is an entirely new set of problems. First, there is the matter of space junk: leftovers from past space missions of all sizes, speeds, and lethality. With all these satellites in orbit, it is possible that debris will start running into them.

Newer LEO (low-earth orbit) and MEO (medium-earth orbit) orbit at lower altitudes than GEOs, allowing them to provide smaller and more energy-efficient spot-beams than more traditional GEOs because of their proximity to earth. The leading LEO broadband constellations are McCaw and Gates' Teledesic, and the cross-investment and marketing effort of Loral Space & Communications' CyberStar with Alcatel Alsthom's SkyBridge will rely on GEO-LEO hybrids. Hughes' Spaceway (through a recent expansion) rely on MEOs or MEO-GEO hybrids. However, spot-beam technology is also making its way to the high-earth orbits of GEOs and Lockheed's Astrolink is one of the major players.

Getting a satellite into a GEO orbit is typically more difficult and expensive than launching smaller, lighter and more easily manufactured LEOs into a lower orbit. However LEOs, with a life span of about five years compared to about 10 of a GEO, LEOs are expected to burn out quicker in that orbit. That means more LEOs must be launched and additional

spares must be on standby, thus higher maintenance cost. The orbit is also at an altitude where a LEO speeding along at 27,000 kilometers per hour (MEOs hit 19,000 km/hr and GEOs 11,000 km/hr) is more likely to be turned into molten plasma by a dislodged bolt of debris hurtling through space.

While GEOs are always in sight of a ground station by virtue of an orbit that matches the earth's rotation, LEOs tend to be overhead for tens of seconds before having to perform complex airborne traffic handoffs to another satellite. With MEOs, things are a bit better, it takes at least one hour to move from horizon to horizon. That short span also means that LEO earth stations must use phased-array antennas (based on current technology) that maintain an active link by keeping at least two satellites in view at all times. The antenna starts a new link before severing one with a satellite moving out of range--all of which adds to terminal complexity and, presumably, cost. However, LEOs address the fundamental problem with GEO's -- latency or the delay caused in reaching and returning from high orbiting GEOs.

Satellite delays can stymie TCP/IP¹⁹ transmissions. The protocol requires quick acknowledgments that packets have been received. GEO services, however, exhibit a 250-msec propagation delay (the time it takes for a signal to travel from earth to the satellite and back). This can stretch longer—up to 500-msecs—when latencies introduced by transmitters/receivers are factored in. This sort of slowdown is simply too much for TCP/IP. When a sending device does not receive the expected acknowledgment, it starts re-transmitting packets it assumes has been lost. All GEO satellite providers are tackling the TCP/IP trouble using spoofing. Essentially, the router at corporate HQ spoofs the Web server that it is connected to, letting it think that the remote user is acknowledging the packets that were sent. Meanwhile, the router simply sends the Web pages over the satellite link to the remote site. Unfortunately, spoofing is not effective with interactive real-time apps like videoconferencing.

LEO and MEO services will not suffer from these sorts of slowdowns. Since these satellites are closer to earth, delays are shorter: 50-msecs and 100-msecs, respectively.

GEOs typically require larger, bulkier antennas and tend to be more bandwidth constricted than LEOs. MEOs are a middle ground between LEOs and GEOs, with an orbit that in some instances must content with greater radiation exposure from the Van Allen belts (about 8000 miles above earth).

One of the great unknowns about MEO and LEO constellations is how well they will be able to handle variations in delay, otherwise known as variable latency or jitter. A low orbit satellite may only spend tens of seconds over a user at a given geographical area and about 15 minutes before it disappear over the horizon, which means that a given transmission may be picked up and passed on by multiple satellites. In addition, because satellite orbits are typically maintained within a range of locations, rather than precisely, the piece-parts of a single transmission can be subjected to varied delays and subsequent packet reordering. In summary, GEO topology is touted as being simpler than that of terrestrial or LEO networks, but the more complex topology of LEO's means that these constellations can tap greater bandwidth for reuse with their tightly focused spot beams and they have the capability to provide coverage for the entire globe. LEOs are expected to produce better results with interactive applications like voice and videoconferencing because of less latency. GEOs are generally considered best for broadcasts and multi-casts applications where LEO mesh networks and transmission might be problematic. The chief differences between these three different types of satellites are summarized below:

	LEO	MEO	GEO
Satellites needed for worldwide coverage (65S to 65N)	48	20	8
Lifespan (yr)	~5	~5	~10
Altitude (km)	500-2k	10k-20k	36k
Time overhead	~15 minutes	2-4hrs	always
Speed (km/h)	27k	19k	11k

Table 8. Chief differences between 3 types of satellites

¹⁹ TCP/IP – Transmission Control Protocol/ Internet Protocol

2. Frequency and Spectrum Consideration

In general, each frequency band has its own unique advantages. While complementing the capabilities of the other bands, the UHF band offers terminals that are operable in adverse weather conditions and are highly suited for mobile operations. UHF primarily supports Single Channel Per Carrier (SCPC) and Demand Assignment Multiple Access (DAMA²⁰) and is highly susceptible to both jamming and heavy congestion.

The SHF band provides a highly desirable satellite transmission medium due to characteristics not available to the UHF band, including wide operating bandwidth to support high data rates, narrow uplink bandwidth, and inherent jam resistance. It supports primarily Frequency Division Multiple Access (FDMA²¹) and some DAMA and is relatively immune to all but heaviest weather. This is useful for focused coverage from multi-beam and spot antennas.

The EHF is the most survivable and secure frequency of the three, but its terminals are the most expensive. It provides low and medium data rates and has the potential to support high data rates. Heavy rain, snow, hail, and other weather conditions degrade EHF service. It supports users with a need for robust protection and survivability, anti-jam, anti-scintillation and LPI/LPD. It is primarily used with TDMA²² services.

²⁰ DAMA - User request access to the satellite when they need it and when satellite resources are available.

²¹ FDMA - Satellite frequency band is divided into many small sub-bands, or narrow channels, and each user, or earth station is assigned to one or more of these channels.

²² TDMA - Allows many users to communicate on the same frequency but on different times.

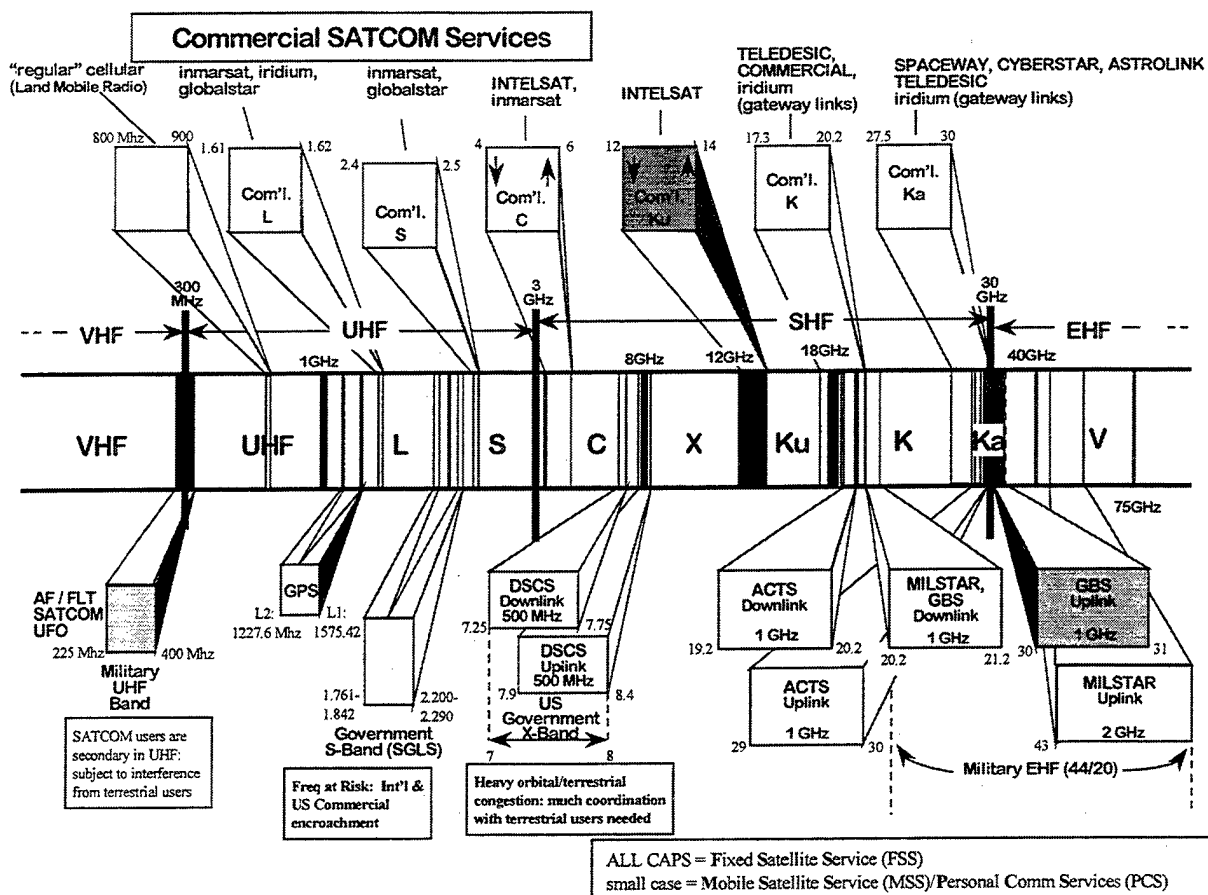


Figure 6. Summary of Frequency band from [Ref. 12]

The UHF frequency band, including the L- and S-bands, are often used to provide assured access but are the easiest to jam. The X-band is a valuable spectrum and is being used as one of the frequencies for common data link in the line-of-sight mode as well as providing secured access for services needing limited or moderate AJ capability. A summary of each frequency band is listed in Figure 6.

C-band (SHF): A frequency often used for data transmission. C is at 6 GHz for the uplink and 4 GHz for the downlink. Hughes Network systems is the principal provider of C-band equipment, which is used primarily in Asia, Africa and Latin America.

Ku-band (SHF): Frequencies often used for satellite data transmission. Ku is at 14 GHz uplink and 12 GHz down. Most commercial satellite operators provide fixed satellite services (FSS) using the C- and Ku-bands. These bands are now congested. None-the-less, Loral's

Cyberstar managed to spearhead broadband services in Mid 98 using existing Ku-band transponder capacity on Loral Skynet's Telstar 5 satellite, this is to capture a slice of the wide-band market before the major Ka players come into action. However, the catch is that the downlink broadcast will be high-speed satellite delivery while the return path will still rely on land-based connections. The Loral's planned constellation is still a 2-way high-speed satellite link in Ka band, which will only be in place after 2000.

The most significant technical impetus was the September 1993 launch of NASA's Advanced Communications Technology Satellite. ACTS proved that powerful satellite with onboard processing and spot beams could blast through what had been impermeable rain clouds to tap huge Ka frequency reserves. The high frequency of Ka also means low-end earth stations as small as a briefcase could come to market for \$1,000 or less. In theory, the Ka-band can support up to 1.2 gigabits. A key advantage of Ka is that there is sufficient new bandwidth to provide two-way services. In the U.S., the industry is now applying for Ka-band frequencies. Organizations such as Hughes, Lockheed Martin Corp., AT&T Corp., Teledesic, and GE American Communications have filed applications with the FCC to participate in the next generation of satellite services using Ka-band frequencies. These applicants seek to use Ka-band spectrum to provide high-speed computer links, video telephony and multimedia services direct to small, low-cost dish antennas at homes and businesses in the United States and elsewhere.

V-band (EHF) above 30 GHz, is the object of considerable research and development. Above V-band is the still faster millimeter wave band, which is expected to bring faster transmission capabilities and smaller terminal size. These higher frequencies were pioneered by the DOD's Milstar satellite. Because V-Band and EHF allocation recently got underway, most experts do not see much more than regulatory activity in the near future; especially given that it took about three years for the mobile satellite industry to move from frequency allocation to reality. Because of the bandwidth these systems afford, they are primarily expected to be used for bandwidth intensive activities like trunking. Some of the systems that are filling for license from FCC are but not limited to, Spectrum Astro's Aster Satellite System, Loral's CyberPath.

TRW's Global Extremely High Frequency Satellite Network (GESN) Hughes' Expressway, and PanAmSat's V-Stream.

3. Inter-Satellite link (ISL)

Newer LEO, GEO and MEO systems also plan to use proprietary spaceborne switching between satellites, relying on intersatellite links pioneered by the Department of Defense's Milstar (Military Strategic and Tactical Relay System) and used for space shuttle communications. These links are one of the toughest technical challenges in these already highly complex systems. Satellite-to-satellite communications will have to take into account issues like power differences between satellites, routing around congested portions of the sky, and beaming in on satellite targets that move within a range rather than along a precise path. This becomes even more tricking with global LEO constellations, since their orbit also requires constellations much larger in size--a minimum of about 48 birds versus about eight for GEOs. Further complicating the issue is the fact that ATM²³--or ATM-like protocols--is being used by most of the broadband providers. During a satellite-to-satellite handoff, ATM cells could get smeared between satellites [Ref. 10]. This might reorder cells--something ATM does not accommodate well. The upside to intersatellite links is they promise an improved way for high-speed traffic to move beyond the boundaries of a single satellite footprint. Today, delays are inherent in systems in which traffic is first shipped to the sky only to return and travel along ground links until it can be shipped back up to another satellite and then down again to its destination. Systems without inter-satellite link sometimes have too many hops from sky to earth and that means dreaded latency.

The downside inter-satellite link is that each satellite has to have more communications and tracking hardware, more intelligence and therefore a higher price. Also, the performance gain may not be tremendous (a few hundredths of a second) depending on application.

4. Frequency Reuse

Traditionally, satellites have relied on passive Bent Pipe²⁴ architectures that receive a transmission, then broadcast it across a huge GEO (geo-stationary earth orbit) cell. These footprints can take in large geographic areas. Most emerging wide-band systems will include new onboard processing systems capable of caching information, instead of simply re-broadcasting it back to earth. This stored information is then switched to one of many small cells that overlay the satellite's footprint. Traffic is more precisely targeted to its destination and this "spot-beam" approach enables a frequency serving a single cell to be reused beyond that cell and those immediately abutting it. With spot-beam frequency reuse, as well as the new bandwidth now made available with Ka, symmetric links become economically feasible. The high frequencies in the Ka band could also mean that less power and smaller antennas can be used on earth.

5. Access Methods

Since Satellite Network uses wireless access, communication channels are not dedicated to terminals on a permanent basis. The channel resources associated with a cell are shared among terminals in that cell, with capacity assigned on demand to meet their current needs. This flexibility is to allow handling a wide variety of user needs: from occasional use to full-time use; from bursty to constant bit-rate applications; from low-rate to high-rate data; from low usage-density areas to areas of relatively high usage density. A multiple access scheme implemented within the terminals and the satellite serving the cell manages the sharing of channel resources among terminals. Additionally, some of the properties inherent to these access schemes also provide a certain degree of security, which prove valuable. The following table illustrates the advantages and disadvantages of basic access methods which most of the

²³ ATM - Asynchronous Transfer Mode. ATM technology is used to transmit data in packets of a fixed size. The data packet size used in ATM is relatively small. By transmitting data with a small constant packet the network is not overloaded with one single type of data packet. ATM can support data rates from 25 to 622 Mbps.

²⁴ Bent pipe: A type of earth-to-satellite-to-earth signal relay that does not involve any significant spaceborne processing. Bent-pipe architectures are sometimes referred to as big repeaters in the sky.

broadband access schemes are based on, such as the Teledesic's Multi-Frequency Access (MF-TDMA) on the uplink and Asynchronous Time Division Multiplexing Access (ATDMA) on the down link.

Access method	Advantages	Disadvantages
FDMA (Frequency Division Multiple Access)	<ul style="list-style-type: none"> • Uses all available bandwidth 	<ul style="list-style-type: none"> • May cause inter-modulation • Frequency reuse is only possible with sufficient spatial isolation to avoid co-channel interference • Bandwidth cannot be easily assigned to another user since user are assigned fixed amounts of bandwidth • Less capacity than CDMA
TDMA (Time Division Multiple Access)	<ul style="list-style-type: none"> • Efficient use of transponder bandwidth • Provides economic benefits in heavy route networks and maximum output • Prevents interference between users by strict adherence to time slot schedules • Allows variation in allocation (more or fewer timeslots to the user) of timeslot based on current user needs • Has much less stringent power control requirements, since interference is controlled by time slots allocation instead of by processing gain resulting from coded bandwidth spreading 	<ul style="list-style-type: none"> • Creates transmission delay for other earth stations waiting to use the transponder bandwidth • All sites must "burst" at the network's capacity data rate which is inefficient use of the spectrum • Requires large earth segment investment due to the greater RF power and larger antennae sizes to support each site bursting at capacity • Can be expanded but there is a limit to the number of sites that a given burst rate can accommodate • Relies on spatial attenuation to control intercell interference
DAMA (Demand Assigned Multiple Access)	<ul style="list-style-type: none"> • Mainly used in digital telephony • Economical because of dynamic allocation of channels and efficient use of transponder • Reliable and easily deployed • Expansion is simple and affordable 	<ul style="list-style-type: none"> • No dedicated station-to-station trunk group assignment • Available interfaces to the public networks are limited and require additional signaling converters to work properly
SCPC/ MCPC (Single Channel Per Carrier/ Multiple Channel Per Carrier)	<ul style="list-style-type: none"> • Digital SCPC/MCPC are advantageous in their low start-up costs for small networks • Reliable, economical, and easily deployed 	<ul style="list-style-type: none"> • Providing routing is difficult due to the use of control channels in an analog system • Connections between remotes must be established through the hub, resulting in a double satellite hop with an additional delay
CDMA (Code Division Multiple)	<ul style="list-style-type: none"> • Very little or no frequency jamming because CDMA design affords some flexibility in parameters such as center 	<ul style="list-style-type: none"> • Vulnerable to the "near and far" problem- the problem of very strong undesired signals at a receiver

Access)	frequency, spread rate, and power level <ul style="list-style-type: none"> • Provides a higher performance and a larger capacity Frequency reuse exists without causing excessive interference (i.e., co-channel interference) • Security - codes can only be decoded by the intended receiver 	swamping out the effect of a weaker desired user's signal <ul style="list-style-type: none"> • High initial equipment cost
Spread Spectrum	<ul style="list-style-type: none"> • Prevents interference Security, only the intended device can decode the spreading pattern • Mitigates multipath fading and interference on radio links because the wide bandwidth introduces frequency diversity • Higher capacity comparable to non-spread access methods 	<ul style="list-style-type: none"> • Higher equipment cost • Large amounts of bandwidth are required

Table 9. Advantages and Disadvantages of Access Methods from [Ref. 13]

6. Pricing

The big question on the minds of network planners is pricing. Most businesses will not want to calculate T1 duty hours or buy into pricing models that are primarily usage-based, especially when the rest of their service providers (i.e., terrestrial) are moving to flat-rate pricing models. The options are hard to compare, because satellite services will involve connect and disconnect time, which is not a factor with leased terrestrial T1. However, survey [Ref. 14] shows that most of a handful of next-generation players are expected to charge rates comparable to or competitive with existing terrestrial services. The author is skeptical considering the investment required to get some of these system running, such as Teledesic which already forecast a \$9 billion start up charge (total build and launch cost) which some critics already said is low.

One thing that is clear is next-generation providers will have more pricing flexibility than traditional Very Small Aperture Terminal (VSAT²⁵) services that require customers to order specific satellite time and charge the customers for that bandwidth even if it is not used.

However these new satellites will never be able to match the economics of fiber with heavy continuous traffic on dense routes where all the capacity of the infrastructure is rigidly dedicated to locations and users regardless of whether they are actually using it at any particular moment. The strategy of course, is going for the last mile, that is area where very little high-speed infrastructure exists today.

Pricing also will have to be on target for low-end antennas, with some experts expressing skepticism that providers will be able to come in at \$1,000 or less--especially for the phased-array antennas mandated by LEO systems. One likely option is subsidizing those terminals if their price exceeds the \$1,000-or-less acceptance level.

7. Market Strategy

Some of the satellite providers are focused on wholesale services to resellers and other service providers. Teledesic and Skybridge say they plan to sell their services on a wholesale basis that is to regional and national telecommunication providers. Others, who aim to offer direct services to large companies as well as wholesale, include Lockheed Martin's Astrolink, and Hughes' Spaceway. Loral's CyberStar is the only provider that plans to concentrate on direct sales to large and small businesses as well as consumers.

Eventually, big businesses are expected to push to receive services directly from their satellite providers, but it makes sense for these providers to concentrate on a wholesale strategy. U.S. satellite providers must win the approvals of the FCC, ITU and each country in which they will provide service. By partnering with nationwide service and terrestrial telecommunication providers and giving them a piece of the action, constellation providers can make many accesses and competing-frequency use problems might vanish. Most broadband satellite providers, like Teledesic, are either taking a strictly wholesale outlook or saying that

²⁵ A VSAT is a private satellite network that provides data and voice communications between a central hub and multiple locations for large businesses. VSAT offers point-to-multipoint communications capability on a global basis.

they are willing to accommodate a few extremely large businesses or organizations. In many instances, their logic is that it can be difficult to convince national providers to give up frequencies and allow satellite competition on their own turf unless they give national providers a piece of the action. So, most satellite say they will partner with existing national providers-even when they have their own intersatellite links that technically permit bypass of national entities. This political side of the satellite equation is widely considered to be much more challenging than even the tough technical issues at hand.

8. Security and Global Billing

As mentioned in Chapter II, protection of user data being packaged up and broadcast into space is only incidental and mainly relies on the access technologies that these systems use. They are a combinations of code division multiple access (CDMA), time division multiple access (TDMA), frequency multiple access (FDMA), and a bunch of other xDMA protocols, making it difficult as it will be to intercept a digital signal. On top of that, many of the networks will offer some kind of internal security systems. However, exactly what kind of securities system will be employed is still murky at this point of time. All of them were aware of the potential security concerns that customers would have. Few, however, had concrete solutions. Some can only say that it does involve encryption. Additionally, second-tier security at the user level will come by way of public- key encryption.

Most leading broadband satellite companies are unwilling to discuss security, and the few that are less closemouthed present rudimentary information. Loral Space and CyberStar plans to employ authentication; Teledesic will use link encryption and other options; Hughes Electronics' Spaceway "will contain mechanisms to support strong authentication and provide data with support for key agreements and management," the provider says.

Competition is one reason for secrecy, but the primary motivation probably has more to do with the fact that many next-generation satellite systems switch traffic between and among nations and global security policy has all the continuity of a litter-strewn parking lot in the big

city. The second major problem is that the bulk of these providers falls under U.S. restrictions on the export of strong encryption, whether that encryption is used to protect customer information or to secure network resources, such as satellite controls, billing or other vital information. However, even if the providers find a way to surmount export issues, they still face a very fractured world of multinational security policies.

One possibility is for US based satellite companies to try to win permission to launch their satellites with strong encryption and then negotiate to whatever encryption level is mutually satisfactory to the nations involved. There are hints that some satellite providers may take such a tack. Similarly, encryption policies are also expected to be discussed as part of the nation-by-nation negotiations some providers are pursuing to secure spectrum and access to their services. In the simple form, that is to come up with a global or regional agreements that would allow satellite providers to protect their own traffic as long as they don't offer encryption as a customer service. If users want security, they have to add it themselves. But is not so different from running private business over any public network, most user would not engage in trusted transactions over the Internet and most likely would purchase some kind of encryption software. In DOD perspective, one objective would be to develop something to ensure seamless interface and maximum protection.

Global billing is shaping up as another tremendous political and technical issue. If usage billing is adopted, one potential approach may be to use firmware installed in broadband transceivers to facilitate prepayment for time-based services. This would reduce the high cost typically associated with the centralized accounting and billing systems needed to reconcile multi-user, multi-provider and multinational services. It could also reduce costs associated with delinquent account collections, lowering overall user charges and providing business with better account control. The possibility of the user accepting this 'pre-paid' concept still remains a question.

C. POSSIBLE CANDIDATES

Section B and Chapter II illustrated some of the key features that need to be considered when selecting the appropriate wide-band systems for military usage, which is by no means complete. However based on the data available, an initial screening will be done, and it is in the author opinion's that the possible candidates are those who have displayed the greatest potential to be successful. In other words, who have backers with deep pockets and have obtained the necessary regulatory approval to get into the wide-band market early (normally those who get their financing and market first will be most successful). At the moment, the Ku and Ka band providers prove to be the most promising as those system who are venturing into V or higher band operations are still at the infancy stage. The potential candidates providing wide-band systems include Astrolink, Cyberstar, Skybridge, Spaceway and Teledesic.

1. Teledesic

Teledesic LLC, founded in 1990, is building a global, broadband "Internet-in-the-Sky" telecommunications network based on a constellation of 288 low-Earth- orbit (LEO) satellites with an estimated aggregate bandwidth of 2.88 Tbps; 10 Gbps (each direction) for each satellite. The network is designed to provide affordable fiber optic-like (global access including polar-regions) access to advanced telecom services such as videoconferencing, interactive multimedia and real-time two-way digital data transmission.

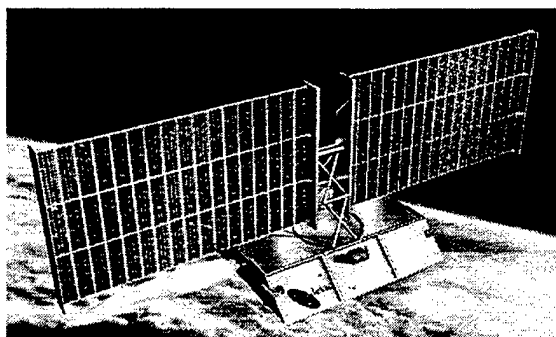


Figure 7. The Teledesic's LEO satellite from [Ref. 15]

Teledesic's primary investors are Craig McCaw, Microsoft Chairman Bill Gates, Motorola, Saudi Prince Alwaleed Bin Talal and Boeing. With Motorola tapping its experience with Iridium (a 66 LEO narrow band system) and Celestri (a proposed 64 LEO & 9 GEO broadband constellation that has been dissolved upon the merger with Teledesic) will lead the international industrial team to develop and deploy the Teledesic system. Boeing and Matra Marconi Space round out Teledesic's founding industrial team. Design, production and deployment are expected to cost \$9 billion, first launch expected in 2000 and service is targeted to begin in 2003. Teledesic completed the system design and filed the Federal Communications Commission application in 1994. The FCC license was granted in 1997. Teledesic cleared its last significant regulatory hurdle when the International Telecommunications Union's (ITU) 1997 World Radiocommunication Conference in November 1997 finalized its designation of international radio spectrum for use by non-geostationary fixed satellite services. A brief summary of the timeline is as follows:

1990	Company founded
1994	Initial system design completed; Federal Communications Commission application filed
1997	FCC license granted; World Radio Conference designates necessary international spectrum for service
1997	Complete Detailed design
1998	Motorola, The Boeing Company and Matra Marconi Space join efforts to build the Teledesic system
1998	Full Scale Development
2000	Begin production
2001	First launch of constellation
2002/3	Service targeted to begin

Table 10. Teledesic Timeline

Teledesic does not intend to market services directly to users, but will provide an open network for the delivery of services by local telephone exchanges and telecommunication authorities in host countries (where the benefits of doing so is already discussed in section B.7). Ground-based gateways will enable service providers to offer seamless links to other wireline

and wireless networks. Service providers will set end-user rates, but Teledesic expects rates to be comparable to those of future urban wireline services for broadband access.

The Teledesic Network will operate in the high frequency Ka-band of the radio spectrum and uses a constellation of 288 operational interlinked low-Earth orbit satellites divided into 12 planes each with 24 satellites to provide global access to a broad range of voice, data and video communication capabilities. Through its global partnerships, the Network provides switched digital connections between users of the Network and, via gateways, to users on other networks. A variety of terminals accommodate "on-demand" channel rates from 16 Kbps up to 2.048 Mbps ("E1"), and for special applications up to 1.24416 Gbps (This represents access speeds more than 2,000 times faster than today's standard analog modems).

Teledesic system's low orbit also eliminates the long signal delay normally experienced in satellite communications and enables the use of small, low-power terminals and antennas. Antenna size is estimated to be approximately 16 inches.

The Teledesic Network intends to provide a quality of service comparable to today's modern terrestrial communication systems, including fiber-like delays, bit error rates less than 10^{-10} , and a link availability of 99.9% over most of the United States. The 16 Kbps basic channel rate supports low-delay voice coding that meets "network quality" standards.

The initial Teledesic constellation will support a peak capacity of 1,000,000 full-duplex E-1 connections, and a sustained capacity sufficient to support millions of simultaneous users. The actual user capacity will depend on the average channel rate and occupancy. The system will provide 24 hours seamless coverage to over 95% of the Earth's surface and almost 100% of the Earth's population.

2. Spaceway

SPACEWAY, a business unit of Hughes Communications, Inc. (HCI), recently announced that it was expanding its 8 GEO Spaceway to become a 16 GEO, 20 MEO global constellation. FCC approved original filing for operation of 8 GEO satellites in May 1997; however, ITU approval is still underway. The latest expansion was filed in Dec 97. This MEO-GEO hybrid system will be able to provide ubiquitous coverage in four main regions: North America, Asia Pacific, Latin America, and Europe, Africa and the Middle East if the second filing is successful. Each regional system will begin with two satellites with the potential of up to four satellites per region.

The first regional system is expected to go online in 2001, where Hughes expects to launch one to four GEOs from an eight-GEO base costing about \$3 billion. (The new expansion is another \$4.7 billion. The last eight GEOs, are expected to pack a bunch-60 Gbps duplex per satellite versus 35.2 Gbps collectively for the first eight. These later GEOs are part of the EXP expansion, while the MEOs come under what is called the NGSO expansion. Both EXP and NGSO are Ka-band systems. Hughes will rely on onboard processing, spotbeam technology and intersatellite links in its expansions.

Hughes decided to invest in global MEOs in an inclined orbit of about, 352 kilometers because of "their economics." The MEO expansion is targeted at latency-sensitive applications and calls for antennas of about 12.5x12.5 inches for up to 2Mbps; about 20.5 inches for up to 10Mbps; and 2 meters for up to 155Mbps. The GEO expansion is primarily aimed at intercontinental and intra-continental trunking and multi-casting at up to 155Mbps, with 99.99 percent availability and 3.5 meter terminals. A summary of the ground terminal offer by Spaceway is listed as follows:

Family of Spaceway Terminals	
Standard USAT	66 cm, 384 Kbps Uplink burst
Enhanced USAT	1.2 m, 1.5 Mbps Uplink burst
Broadcast	3.5 m, 6 Mbps Uplink burst
Downlink on All	108 Mbps

Table 11. Family of Spaceway terminal

According to Hughes VP Edward Fitzpatrick "the advantage of Spaceway over existing systems like his DirecPC is improved connectivity, improved bandwidth and data rate, greater versatility and smaller antennas". For example, he says businesses will be able to tap up to 6 Mbps from Spaceway using antennas that are only about 66 cm wide. Those terminals (66 cm) are expected to cost about \$1,000 in volume and charges will be based on resources used by customer and will be competitive with terrestrial system. Target Markets are enterprise, small and medium business, home-workers and consumers, while emphasis is still on wholesale.

Hughes has also applied to the FCC for V-band frequency to be used in a follow-on higher-speed system known as Expressway. Fitzpatrick says to look for Expressway in the 2004 to 2005 timeframe. Hughes expects Expressway to be used primarily for high-speed point-to-point trunking.

Finally, Hughes owns majority shares in PanAmSat Corp., one of the largest existing satellite providers. PanAmSat actively promotes ISP (Internet Service Provider) caching over its constellation. For example, one of Japan's largest ISPs is working with PanAmSat aggregating Internet traffic in the U.S. and delivering it via antennas to smaller ISPs. PanAmSat has 17 satellites and plans to launch six more by late 1999. Additionally, Hughes is also the main contractor of DOD's SATCOM programs such as GBS and the retired Navy's LEASAT, which definitely gives Hughes an edge over others in the area of business with DOD.

3. Astrolink

The Astrolink venture is an initiative of Lockheed Martin (the leading contractor of DOD's Milstar program). It will be an independent company jointly owned by Lockheed Martin and international network operators (no details of who exactly they are). Armed with the on-board processing and spot beam technology which have been demonstrated in the Advanced Communication Technology Satellite (ACTS) program, and intersatellite crosslinks demonstrated on Milstar. The space-based component of Astrolink's network will be a GEO constellation of nine Ka-band satellites with an estimated aggregate bandwidth of 6 Gbps per satellite. These nine satellites will occupy five orbital slots (pending ITU coordination). First satellite in service expected in 2001 and will provide worldwide coverage (no polar coverage) once four satellites are in orbit; as traffic increases the additional five will be launched to augment the constellation. Total build and launch cost is estimated at \$6 billion.

Through its global partnerships, the Network provides switched digital connections between users of the Network and, via gateways, to users on other networks. A variety of terminals accommodate "on-demand" channel rates from 64 Kbps up to 10.4 Mbps. A compilation of Astrolink's customer bandwidth and terminal options are as follows:

Small Office Home Office	Data rates up to 416 kbps,	65 cm dish	2 watts power, terminal EIRP up to 49 dBW, G/T is 18 dB/K.
Medium enterprise	Data rates up to 2.1 Mbps	100 cm dish	12 watts power, terminal EIRP 56 dBW, G/T is 18 dB/K
Major enterprise	Data rates up to 10.4 Mbps	1.8m dish	15 watts power, terminal EIRP 62 dBW, G/T is 24 dB/K
Regional Gateways	Data rates up to 110 Mbps	3 m to 5.5 m (depending on geographic location)	Up to 100 gateways will connect Astrolink to terrestrial networks worldwide.

Table 12. Astrolink customer bandwidth and terminal options

Terminals of size up to 100 cm are expected to cost from under \$1,000 to \$2500 and charges will be based on resources used by customer and will be competitive with terrestrial system. Market strategy is similar with Spaceway, Lockheed plans to market Astrolink services

to business and common carrier providers worldwide. Being GEO in nature, no polar coverage is expected.

4. Cyberstar

Loral plans to phase in its CyberStar services through leased facilities over the Skynet satellites (Ku band) it purchased from AT&T for \$478.1 million. Testing of this system began at fall 97 and full service broadcast at 30Mbps began at summer 98 (this is a high speed broadcast service with return path running at 384 Kbps still relying on land based connection)

A second phase calls for providing two-way Ka-band service at 500Kbps uplink and 3-6Mbps downlink. Amount of aggregate bandwidth for each satellite is not available at the moment, but estimated to be approximately 4.4 Gbps. The Timing for that phase is now hovering at the year 2000 or beyond. This second phase constellation consists of three Ka GEOs with a total build and launch cost estimated at \$1.6 billions. FCC approval for these Ka GEOs was given at May 1997.

Today, Skynet includes three satellites, but Loral will be replacing one of those aging satellites this year and plans to add two more satellites to the constellation at the beginning and end of 1999. Three more Ku-band GEOs will arrive from the finalization of Loral's purchase of Orion. One of those GEOs is already in orbit, a second is slated for 1998 and a third for 1999. Thus, Loral's Ku constellation will consists of six satellites in the Geo-synchronous orbit. CyberStar President Ron Maehl says CyberStar will tap Orion's groundstation facilities to extend its services to Europe and the Middle East.

Loral's expanding international presence also comes in the form of a 75 percent stake with Telefonica Autrey in Satellites Mexicanos, S.A. de C.C. and its 39 percent stake in Globalstar, a 56-satellites mobile voice system that will compete with Iridium and ICO.

Through a \$30 million cross investment with Alcatel Alsthom's SkyBridge 64-satellite LEO constellation, Loral plans to pursue integrated marketing to better serve real-time and interactive applications and the goal is to "develop the market" before deploying the new satellites.

Maehl expects two-way PC terminal and equipment for CyberStar to cost about \$1,300, with the cost cut to about \$300 for receive-only units. For large businesses the company is exploring using \$150 PCI cards to communicate with a central receive dish. Server-based communications are also being considered. Antenna size for Ku band receiver is about 16 inches and those operating under Ka band will be similar to those offered by Astrolink.

One of the truly unique aspects of CyberStar's business plan is its emphasis on businesses and consumers in addition to selling to other service providers. In fact, Maehl says the businesses most interested in CyberStar's upcoming services tend to be large Silicon Valley companies, server and network systems providers, and the more traditional value added network providers and carriers. The service is focused on the Americas, Europe and Asia. Being GEO, polar coverage is not expected.

Loral's purchase of Orion plays particularly well into CyberStar's end-user emphasis, since Orion already serves about 260 private businesses and ISPs in 47 countries. The end-user emphasis may also lie behind Maehl's belief that security is of "primary importance" to CyberStar. He says the service will include smart-card based authentication, although a decision has yet to be made on encryption.

Maehl says CyberStar is still examining the possibility of ISLs with SkyBridge and its own satellites, but appears to be leaning away from the technology because of technical problems associated with multiple spaceborne hops and the fact that ISLs use up critical power that could be directed toward the earth.

Finally, Loral has an edge with its affiliation with Space Systems Loral, which is able to buy launch vehicles in bulk. Loral is also looking beyond Ka-band to higher frequencies in the more distant future. Recently, Loral applied to the FCC for higher frequencies (V-band) for its CyberPath, a \$1.2 billion system of 10 GEOs (four were included in the application) that would rely on \$1500 earth stations for broadband communications.

5. Skybridge

In June 98, SkyBridge Limited Partnership, a satellite-based telecommunications system providing global broadband access via local operators, announced that it is increasing its global system capacity by expanding its proposed satellite constellation from 64 to 80 Ku band's LEO satellites to meet market demand. The budget necessary for implementing the SkyBridge system amounts to US\$4.2 billion dollars. The costs include: development of prototypes for the ground and space segments, manufacturing and launching the constellation, development and installation of the satellite control segment, launch and insurance. Service is scheduled to begin towards the end of 2001 (with half the planned constellation) and aggregate capacity is set at 200 Gbps (2.5 Gbps per satellite, up to 2Mbps uplink and 60Mbps downlink). Terminals will range from personal units to those designed for residential or corporate buildings and include an outdoor component as well as a system interface such as a PC, set top box, PABX or other device. Personal terminals for individual subscribers will feature a small 45-cm diameter radome at USD 700. Multi-user terminals for corporate and communal residential use will be able to serve several dozens of users with a 70-cm diameter radome.

SkyBridge plans to complement and extend terrestrial networks and help user to solve the "last mile" problem by providing an instant broadband connection to users that previously only had narrow-band access. Market strategy is to deliver services locally through national and regional telecommunications operators and other service providers. A SkyBridge spokesman says the constellation has a conservative target of 20 million users. Services are targeted to North America, Europe and parts of Asia initially. ITU had already approved SkyBridge frequencies and the consortium is awaiting FCC license.

The SkyBridge constellation consists of two constellations of 40 satellites orbiting at an altitude of 1469 km. The constellation provides permanent worldwide coverage between latitudes $+68^{\circ}$ and -68° . While SkyBridge is new in the sense that it is a 80-bird LEO constellation without the delays inherent in GEO systems; it is old in the sense that it intends to rely on Ku-band frequencies. SkyBridge also plans to use rely extensively on traditional ground-station communications versus intersatellite links.

Whether this blend proves a winning strategy remains to be seen. Certainly, system complexity is reduced without ISLs and the political job of securing access rights around the globe becomes easier if existing providers tie into some 200-ground stations planned for SkyBridge.

The downside to this approach is that SkyBridge (and other that may share spectrum) must deal with the complexity of having two satellites in sight whenever interference with existing frequency allocations becomes a possibility. Additionally, spot-beam reuse of frequency is more difficult in the Ku band and may prove limiting from a bandwidth perspective.

Some analysts also point to SkyBridge's consortium led by Alcatel, as having less of a name in space than players like Hughes. However the simplicity of promised by SkyBridge coupled with Alcatel's ATM know-how and its big league presence in Europe (although SkyBridge is technically incorporated in Delaware) gives Skybridge an advantage. Moreover SkyBridge has rounded up a large number of financial backers, including important Asian companies like Toshiba. Finally, SkyBridge has a \$30 million mutual cross-investment with Loral that intertwines the companies' marketing approaches.

D. SUMMARY

The promise given by space-based broadband systems have to face some reality. Firstly, unforeseen complications can easily surface during the initial running of these complex and expensive constellations before 2002. Secondly, with individual constellation efforts costing as much as \$9 billion (or more), the race for market share, with all of the ugliness, techno-sparring and hype, has already begun. Many satellite systems will live and die based on this verbiage and its ramifications for ongoing financing. While the number of competitors is considerable today, rapid and dramatic consolidation is expected over the next few years.

For this research study, the author manage to extracted some relevant parameters (as shown in Table 13) for the assessment of their potential for military usage. Obviously, there is an enormous amount to learn: architecture, potential pricing and the successful handling of the hurdles ahead. In this highly competitive industry, extracting information can be extremely difficult, thus these data collected is by no means complete, but is intended to provide a first hand screening and appreciation of the current market status.

Table 13. Summary of Commercial Wideband Satellite System

	Cyberstar	Astrolink	Teledesic	Spaceway	Skybridge
Backers	Loral Space & Communications, Alcatel	Lockheed, TRW was selected as payload contractor in February 1998.	<p>Bill Gates and Craig McCaw have private shareholdings and own the majority of the shares at present. In Apr-98, His Royal Highness Prince Alwaleed Bin Talal Bin AbdulAziz Al Saud of Saudi Arabia invested USD200 million for a 13.7% stake in Teledesic. In May-98, Motorola received a 26% stake in Teledesic for an investment of USD750 million. Design and development work from Celestri will now be re-directed to the new joint project. Motorola will now be the prime contractor. Previous to the Motorola deal, Boeing had invested USD50 million for a 5% stake in the company, with an option on a further 5% for USD50 million (not yet exercised).</p>	GM-Hughes	<p>Alcatel Space, Loral Space & Communications, Mitsubishi, Sharp, Spar Aerospace (Canada), Aerospatiale (France), SRIW(Belgium), Toshiba and Com Dev (Canada).</p> <p>SkyBridge has contracts with China, US, Proton and Arianespace to launch its satellites.</p>
Current Status	Cyberstar introduced service in Apr-98 using existing Telstar Ku-band satellites. A Ka-band GEO constellation is intended to be ready in 2000, and the full operational service expected in 2001 in conjunction with the LEO constellation of SkyBridge	<p>Expected to be in operational service in 2001, with the first satellite in orbit. The global coverage will be achieved using five satellites, with 4 additional ones to meet later demand</p>	<p>Motorola's Celestri project has now been incorporated in the Teledesic system following the partnership announced on May 21 (Teledesic, Motorola, Boeing and Matra Marconi Space). First launch expected in 2000, with operational service in 2003.</p> <p>Teledesic will develop alliances with service provider partners in countries worldwide, rather than marketing directly to end-users</p> <p>Teledesic will enable service providers to extend their networks, both in terms of geographic scope and in the kinds of services they can offer.</p>	<p>The first regional system is expected to go online in 2001. In Dec 97, Hughes filed two new applications with the US FCC for an eight satellite GEO system and a 20 satellite NGSO (non-GEO) system. The original Spaceway architecture is to go ahead as planned</p>	<p>The program has been upgraded from 64 to 80 satellites. SkyBridge is expected to enter service in 2001 with half of its 80 satellites in operation. Full operation is expected in 2002.</p>

	Cyberstar	Astrolink	Teledesic	Spaceway	Skybridge
Use	Internet access, broadband interconnection, VOD and other data services	Data, video, rural telephony	Enterprise nets, Internet access, telecommunicating, multimedia conference	Intranet extensions, remote LAN access, content distribution, e-commerce, telecommuters	General broadband, including LAN to LAN and videoconferencing
Geographic Coverage	Focus on North America, Asia and Europe. The service was introduced just in the US in April 1998 Able to provide coverage from 72S to 72N	Focusing on major landmasses Able to provide coverage from 72S to 72N	Full global coverage including polar regions.	Most of the major continents will be covered except for parts of Asiatic Russia. The bulk of the inhabited world will be covered. Able to provide coverage from 72S to 72N	Focusing on 68N to 68S, Able to provide polar coverage.
Market Strategy	Targeting broadband applications such as Internet and intranet access from low-cost fixed terminals Loral has formed a strategic alliance with Alcatel to market the Cyberstar GEO and Skybridge LEO projects together Concentrating on Direct sale to enterprise & consumer	Lockheed plans to market the Astrolink service to businesses and common carrier providers worldwide, providing high-speed, two-way data services. Wholesale service and sell direct	It aims to provide broadband digital access at an affordable cost to information workers anywhere in the world from fixed terminals Internet/intranet access are likely to be key markets. Wholesale to regional and national telecommunication providers	Spaceway is expected to provide services in areas where the infrastructure is inadequate to meet the needs. The first target markets are likely to include North America. Wholesale & direct	It is primarily aimed at providing broadband access in areas with low or moderate density populations. SkyBridge will be marketed together with Cyberstar. Loral and Alcatel have invested initially USD30 million in each other's system. Wholesale to regional and national telecommunication providers
Altitude (Miles)	22300 (GEO)	22300 (GEO)	839 (LEO)	22300, 6430 (GEO-MEO hybrid)	911 (LEO)

	Cyberstar	Astrolink	Teledesic	Spaceway	Skybridge
Spectrum	Ku(initial) & Ka	Ka; Uplink frequency: 28.35 to 28.6 & 29.25 to 30GHz Downlink frequency: 19.7 to 20.2GHz	Ka-band (28.6 to 29.1GHz uplink and 18.8 to 19.3GHz downlink). Approval for full 500MHz for uplink and downlink was given by WARC-97.	Ka; Uplink frequency: 27.5 to 30.0GHz; Downlink frequency: 17.7 to 20.2GHz	Ku band (12 to 15GHz),
Antenna Size (Est.)	16 inches (initial Ku, 384 Kbps max) 33-47 inches (Ka)	33-47 inches	16 inches	26 - 137 inches	17 - 27 inches
User Terminal Cost (Est.)	\$800(initial Ku); \$1000(Ka)	Under \$1000 to \$2500	\$1000	\$1300	Around \$700
System Cost (Billions)	\$1.6 for KAs + ~ \$1 for the KUs	\$6	Estimated to be around USD9 billion but may change following the Motorola deal.	\$300 for receive only \$3 for the first 8 and \$4.7 for the expansion	\$4.3
First Satellites In Service	Mid 1998 with leased transponder	1 GEO by 2001	2002 (288 LEOs)	2001 (1 to 4 GEOs)	End of 2001
Number Of Satellites	Will use leased Ku; may build 3 Ka	9 GEOs	288 LEOs + 24 spares	16 GEO & 20 MEOs	80 LEOs + 8 spares
Bentpipe On Board Processing	Bent pipe initially moving to onboard with crosslink	Onboard with intersatellite links	On board processing; intersatellite links	On board with intersatellite links	Passive Bent pipe with no intersatellite link

	Cyberstar	Astrolink	Teledesic	Spaceway	Skybridge
Protocols/ Interfaces supported	IP multicast, Digital Video Broadband compliant, T1 and ISDN. Evaluating ATM	ATM architecture supporting TCP/IP, T1, fractional T1, frame relay, X.25 ISDN, compressed voice, telephony	Transparent bit pipe; partners can provide specific interface support	Standards compliant; protocol transparent	Virtually all standard protocols and interfaces (not just transparent bit pipe)
Estimated Aggregate Bandwidth	Not available, estimated to be 4.9 Gbps per satellite	6 Gbps per satellite	10 Gbps per satellite; total 288 Tbps	4.4 Gbps per satellite for the first 8 GEOs; ~7.5 Gbps per satellite for the following 8 GEOs and 20 MEOs	200 Gbps total; 2.5 Gbps per satellite
Customer Bandwidth Options	500 Kbps uplink; 3-6 Mbps down link 30 Mbps broadcast	64 Kbps, 384 Kbps, 2304 Kbps, or 9216 Kbps	16 kbps to 2 Mbps uplink 64 Mbps downlink more than 1 Gbps uplink and downlink possible	16 Kbps to 6 Mbps uplink 108 Mbps shared down link to 155 Mbps in system expansion	Nx20 Mbps downstream and Nx2.5 Mbps upstream
Min Elev. Angle(°)	20	17	40	20	10° for the 64 LEO constellation.
Round trip latency	400 msec	400 msec	40-100 msec	400 msec	20 msec
Modulation/ Multiple Access Scheme	QPSK FDMA/TDMA	QPSK FDMA/TDMA	QPSK MF-TDMA ATDMA	QPSK FDMA/TDMA	Not available
FCC/ITU approvals	FCC licensed ITU underway	FCC licensed ITU underway	FCC & ITU licensed	100% base system for US, ITU underway	ITU licensed FCC underway
National Preapproval Signed	Details not available	Work underway	Will rely on partners	Not available	Will work with national partners

V. ASSESSMENT OF CANDIDATE SYSTEMS

A. INTRODUCTION

As discussed in Chapter IV, five commercial wide-band satellite systems, namely Teledesic, Astrolink, Cyberstar, Spaceway and Skybridge have been proposed. These systems were evaluated given their capability to support DOD's wide-band communication requirements and commercial as presented in Chapter II. This qualitative evaluation is also based on the technical specifications, market strategies and company backgrounds (as discussed in Chapter IV) with rankings assigned from 1 to 5, with 1 being the highest ranking and 5 being the lowest. In the event of a tie as perceived by the author, equal ranking will be assigned. Weightage based on the degree of importance of each in supporting DOD communication requirements will then be applied to determine the 'best value' system. Table 14 illustrates the results of this evaluation. The criteria for the evaluation are delineated in the subsequent sections of this chapter.

Requirements	Teledesic	Astrolink	Cyberstar	Spaceway	Skybridge
Access and Control	2	1	3	1	4
Coverage	1	3	4	3	2
Inter-operability	1	2	2	1	1
Regulatory approval	1	3	3	3	2
Market acceptance	1	2	2	2	1
Quality of Service	1	4	4	3	2
Capacity	1	4	5	3	2
Technical feasibility and other factors	4	3	1	3	2

Table 14. Evaluation of capability to support the requirements

B. ACCESS AND CONTROL

In general, all five candidates should be able to provide prioritization, preemption and dedicated circuit to DOD since their market strategy is focusing on wholesale, where DOD could be one of the 'service provider' subscribing to their network and maintains full control of his own 'customer'. Therefore, the above mentioned factors are just a matter of contract negotiation if DOD decided to utilize one of the wide-band candidate's networks. With regards to running into risks of being denial of service in the time of need, Astrolink and Spaceway stand out as better choices since they are solely US owned and operated. In-addition both have recently co-operated with DOD in the GBS (Hughes) and Milstar (Lockheed Martin) programs.

Skybridge, which is under Acatel Alsthom, a primarily French owned consortium might not give high assurance to DOD in this matter, mainly due to the history of US and French economical and political relationship such as French's arm sales to potential US military rivals. This also indirectly affects the ranking of Cyberstar due to its \$30 million cross investment with Acatel Alsthom.

Teledesic, should be a strong contender with majority US based 'rich' backers such as cellular phone tycoon, Craig McCaw; Chairman and CEO of Microsoft, Bill Gates²⁶; Motorola (the developer of Iridium) as well as Boeing. However, the current awkward US Federal antitrust action against Microsoft (with the bulk of the anti-trust action focusing on the prevention of evolving monopolistic corporation) remains a point of concern if DOD were to venture into Teledesic. There may be a chance that Teledesic might not honour its commitment due to bruise egos (even though this might be trivial). None-the-less, most people anticipate that the Microsoft or Bill Gate legal struggles will blow over eventually.

²⁶ Bill Gates' investment is a personal one and not associated with Microsoft

	Access and Control based on relationship with US military and government	Ranking
Teledesic	Mostly US owned backers, but one of the major stake holder currently going through an ant-trust action with the US government	2
Astrolink	Solely US owned company and with history of co-operation with US military	1
Cyberstar	Major stake held by US based company but system going to integrate with an international consortium led by French	3
Spaceway	Solely US owned company and with history of co-operation with US military	1
Skybridge	An International consortium led by a French company	4

Table 15. Access and Control ranking

C. COVERAGE

Teledesic has the additional capability to support users on a global basis because the GEO wide-band systems namely Astrolink, Spaceway and Cyberstar are limited to the landmasses between 72° latitude. Skybridge, is less favorable than Teledesic because it only focusing on latitude between 68S and 68N, in-spite of its inherent capability of global coverage.

The other aspect of coverage as discussed in Chapter II, is the ability of these systems to provide coverage for user on the move and access at the same time in any combat environment including double canopy/jungle, inside a building, in rain and at sea. To avoid obstacles and limit the portion of the path exposed to rain requires that the satellite serving a terminal be at a high elevation angle above the horizon. Out of the five possible candidate systems, a Teledesic satellite can always be viewed nearly directly overhead. This is ensured by having an elevation angle of 40 degrees or higher at all times in all locations. The higher elevation angle enables users to place terminals on most places with an unobstructed view of the sky in all directions. A lower elevation angle dramatically increases the likelihood of obstruction by surrounding buildings, trees or terrain preventing service. In many areas especially at higher latitudes, a low elevation angle can make service impractical or simply impossible. Additionally, signals at high frequencies can also be blocked by rain, especially when sent at a lower elevation angle (longer path thus higher exposure to rain).

Therefore high receive antenna elevation angle is often needed to meet the goals for high Quality-of-Service, reduce user terminal size (higher mobility) and cost. However, it also implies that more satellites will be required (higher startup and maintenance cost) so as to provide the same area of geographical coverage as those using lower earth antenna elevation angle solution. Assessment of the 5 possible wide-band systems with regard to coverage and consideration of the effects due to antenna elevation angle is illustrated in Table 16.

	Coverage	Elev. °	Ranking
Teledesic	24 hrs global coverage including polar regions	40	1
Astrolink	Focus on major continents but with $\pm 72^\circ$ latitude coverage possibility	17	4
Cyberstar	Focus on North America, Asia and Europe but with $\pm 72^\circ$ latitude coverage possibility	20	5
Spaceway	Most of the major continents but with $\pm 72^\circ$ latitude coverage possibility	20	3
Skybridge	Focusing on $\pm 68^\circ$ latitude but with incidental coverage over the polar regions	10	2

Table 16. Coverage ranking

D. INTEROPERABILITY

The DISN architecture utilizes Broadband Integrated Services Digital Network (B-ISDN) as the predominant technology for the fixed environment and Asynchronous Transfer Mode (ATM) in the deployed environment. Cyberstar and Astrolink propose to offer ATM and B-ISDN compatibility with the global terrestrial network thus providing interconnection to the PSTN and DISN. Teledesic, Skybridge and Spaceway advertised that they could support virtually all standard interfaces using transparent bit pipe or protocol, therefore allowing DOD or other organizations such as Internet Service Providers (ISPs) to specify the required interface support. On this basis, these three systems receive a higher ranking than Cyberstar and Astrolink. Ranking result is shown in Table 17.

	Interoperability based on Interfaces and protocol supported by the systems	Ranking
Teledesic	Transparent bit pipe, partners (service providers) can provide specific interface support	1
Astrolink	ATM, TCP/IP, T1 and ISDN	2
Cyberstar	DVB, IP multicast, T1 and ISDN	2
Spaceway	Transparent protocols, partners (service providers) can provide specific interface support	1
Skybridge	Able to support virtually all standard protocols and interfaces, partners (service providers) can provide specific interface support	1

Table 17. Interoperability ranking

E. REGULATORY APPROVAL

Teledesic and Skybridge have received their National license to launch and operate satellite systems as well as ITU allocation of orbital slots and operating frequencies. On the other hand, the other three are only given the National (FCC, since all three are US based system) license to launch and operate their systems in their base country. To-date, none of them have acquired site operation licenses, PSTN²⁷ connection approvals and landing rights²⁸ on nations they going to operate in yet. However, work is underway and most (except Cyberstar) have adopted the approach of partnership with host nation's telecommunication and service providers to gain the necessary approvals as discussed in Chapter IV, which, in the author opinion will have a better chance of success.

Based on the status of regulatory approval, Teledesic is slightly ahead of the other four systems. Skybridge has not received its license to operate in US yet even though it has the license to launch and operate in Europe, therefore receiving a lower ranking than Teledesic. Result of this ranking is shown in Table 18.

²⁷ Public Switch Telephone Network connection approvals: which may provide critical links to other communication systems

²⁸ refers to the placement of terminals on host nation soil

	Regulatory approval	Ranking
Teledesic	FCC license and ITU allocation of Ka frequencies and orbital locations	1
Astrolink	FCC license, ITU underway	3
Cyberstar	FCC license to operate in Ka Band, ITU underway	3
Spaceway	FCC license for the first eight GEOs, ITU underway, the 8 GEOs and 20 MEOs expansion is still awaiting for FCC and ITU approvals	3
Skybridge	ITU allocation of Ku band frequencies and orbital locations and European license to launch and operate satellite systems, FCC license underway	2

Table 18. Regulatory approval ranking

F. MARKET ACCEPTANCE

The wide-band GEOs require larger fixed terminals, thereby inhibiting communication on the move and are more difficult to setup within a reasonable time. The two LEO based systems, Teledesic and Skybridge, claim that their terminals (2 Mbps) can be operated with minimum setup time at a fixed site, if not, on the move except onboard highly dynamic platforms such as aircraft or onboard ship at extreme sea state conditions. Teledesic and Skybridge are attractive options for Military and News organizations where operating sites are relocated constantly. Note that all wide-band systems surveyed are unable to support all of the environmental conditions as stated in Chapter II, therefore terminal hardening is expected if DOD is going to adapt these system for operation in combat environment.

Most providers expect the price of broadband to decline considerably in coming years as satellite systems and terrestrial options, such as xDSL and cable modems, foster a competitive broadband access market. The resulting effect driving the current estimate of service rate that will be comparable or about 10% under terrestrial T1. Pricing of low-end antenna's terminal will come in at about \$1,000 or less. However, some experts expressing skepticism especially for the phased-array antennas mandated by LEO systems. None-the-less based on the advertised pricing, antenna size, transportability and bandwidth option offer to user, ranking is done as illustrated in Table 19.

Assessment on the establishment of customer service systems cannot be done as it is still early at this stage where most of them are still in the development or production stage.

Market Acceptance based on Antenna size and cost						Ranking	
	Antenna size and bandwidth option			Score	Terminal cost	Score	
Teledesic	16 inches, transportable 16K-2Mbps Up link 64Mbps Down link 1 Gbps Up and down link possible			1	\$1000	2	1
Astrolink	Small Office	Data rates up to 416 kbps,	26 inches dish	3	Under \$1000 to \$2500 for the 26 inches and 39 inches respectively	2	2
	Medium enterprise	Data rates up to 2.1 Mbps	39 inches dish				
	Major enterprise	Data rates up to 10.4 Mbps	1.8m dish				
	Regional Gateways	Data rates up to 110 Mbps	3 m to 5.5 m (depending on geographic location)				
Cyberstar	16 inches (initial Ku at 384 Kbps) 33-47 inches (Ka), all stationary 500Kbps Uplink 3-6Mbps Down link 30 Mbps broadcast			5	\$800(initial Ku); \$1000(Ka) for the 16 inches	2	3
Spaceway	Standard USAT	26 inches, 384 Kbps Uplink burst		4	\$1300 for the 26 inches antenna terminal \$300 for receive only	4	4
	Enhanced USAT	59 inches, 1.5 Mbps Uplink burst					
	Broadcast	3.5 m, 6 Mbps Uplink burst					
	Downlink on All	108 Mbps					
Skybridge	17 – 27 inches, the smaller antenna is transportable 20 Mbps Down link 2.5 Mbps Up link for the 17 inches option			2	Around \$700 for the terminal with smaller antenna	1	1

Table 19. Market Acceptance ranking

G. QUALITY OF SERVICE (QOS)

As indicated in Chapter II, QOS refers to the performance guarantees that a network can offer to its users. Quantitative measures of Availability, Delay and Blockage has to be provided by vendor as contractual responsibilities to provide high prioritizes users with timely and accurate transfer of information regardless of system congestion or during periods of high congestion. Since this can only be dealt with during contract negotiation, the author assumes an equal status for all in this perspective.

However, the other factors, like latency for GEOs and jitter for LEOs/MEOs could be used as a baseline for assessment with respect to Quality of Service. Based on the potential problems as discussed in Chapter IV, while any specific latency problem in a protocol or application may be individually solvable in the GEO system by not using the standard Internet or Server protocols such as ATM or TCP/IP, when taken together, these problems are indicative of the business risks of building networks that diverge from terrestrial standards, thus rendering them less favorable.

LEOs, where a given transmission may be picked up and passed on by multiple satellites as satellite orbits are typically maintained within a range of locations rather than precisely, the piece-parts of a single transmission can be subjected to varied delays or jitter and subsequent packet reordering. This however, can be minimized (in-accordance to NASA orbital concept modeling and is now pursued by Skybridge) by creating what is known as an inclined orbital pattern that angles off the equator, but doing so will result in polar regions not being covered. This problem can also be further resolved by using larger memory buffers in earth stations which would allow transmission to be delayed long enough (but shorter than GEOs) so that the playback to the user is at a constant latency. The trade-off here is this type of approach adds complexity to the already challenging task of getting the LEOs airborne and managing it.

The other consideration with an inclined orbit is the smaller the constellation the greater the jitter. This is because each satellite in a smaller constellation will have to serve a larger ground

footprint relative to the footprint served by a larger, denser constellation. If this is correct, Alcatel's Skybridge, with 80 LEOS, could have a greater magnitude of jitter than Teledesic with 288 satellites. Ranking result is as shown in Table 20.

	Orbital type	Number of satellites	Ranking
Teledesic	LEO at 830 miles	288	1
Astrolink	GEO	9	4
Cyberstar	GEO	3 Ka and 6 Ku	4
Spaceway	GEO & MEO (6430 miles) hybrid	16 GEO and 20 MEO eventually	3
Skybridge	LEO at 911 miles	80	2

Table 20. Quality of service ranking

H. CAPACITY

As defined in Chapter II, capacity is the maximum rate of reliable information transmission with a Bit Error rate of no greater than 10^{-10} . All vendors have claimed that their systems are able satisfy the BER threshold of 10^{-10} if not better. The next step is to determine the maximum number of access that a vendor can provide for DOD routine underway operations as well as its' ability to accommodate a surge in capacity in a fairly small region.

Firstly, the vendors' ability to accommodate a surge in capacity, the author is of the opinion a matter of contract agreement and vendors upholding their responsibilities to redirect and prioritize their resources (will be approximated in the following paragraphs) to DOD in time of need. The selection and ranking considerations are already discussed when dealing with subject, Access and Control (section B of this chapter).

Assuming that the satellites' coverage area of all five systems have the same user distribution, a simple model²⁹ [Ref.17] using the advertised satellite's capacity, attitude and earth antenna's elevation angle has been adapted to compute the maximum capacity per unit geographical area. Thereby determining the wide-band system credibility of the maximum

²⁹ The model used to calculate the distance covered in a single hop based on simple geometric consideration of a spherical earth is adapted from Chapter 5 of Paul Rohan 'Introduction to Electromagnetic Wave Propagation', Artech House, 91. T

number of user accesses. The result obtained based on this model (as illustrated in Figure 8) is shown in Table 21.

In the absence of information such as number of projected users and maximum capacity in each satellite footprint, the author is of the opinion that this could be the best analogy before any contract negotiation for an 'assured promise' from the vendors.

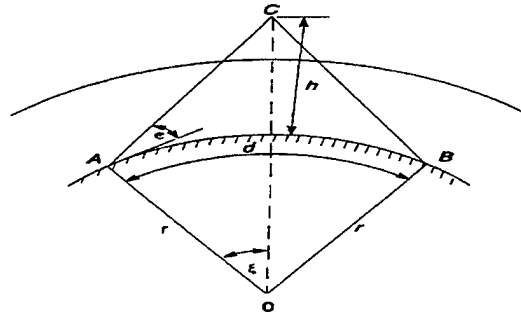


Figure 8. The area covered by a satellite at height h with elevation angle ε from [Ref.17]

Using side angle relations in plane triangle

$$\xi = 180 - (\varepsilon + 90) - \sin^{-1} \left(\frac{r \sin(\varepsilon + 90)}{h + r} \right)$$

$$d = 2r\xi$$

Where

ε is the earth antenna elevation angle with respect to local horizon

r is the earth's radius = 6378Km or 3963 miles

h is the satellite altitude

2ξ = the angle subtends by 'd'

$$\text{Coverage area per satellite} \sim \pi d^2 / 4$$

Therefore max capacity per unit area covered

$$C/A = \text{max capacity per satellite} / \text{coverage area per satellite}$$

Assuming same user distribution in each satellite footprint

$C/A \equiv \text{max number of users/ coverage area}$

	Max capacity per satellite (Gbps)	ϵ , Elevation angle (degrees)	h, Altitude of satellite (Km)	Coverage (Km ²)	C/A, Capacity per unit area bps/Km ²	Ranking
Teledesic	10	40	1350	5.27E+06	1.90E+03	1
Astrolink	6	17	35900	1.89E+08	3.17E+01	4
Cyberstar	4.9	20	35900	1.73E+08	2.83E+01	5
Spaceway ³⁰	7.5	20	10352	1.09E+08	6.90E+01	3
Skybridge	2.5	10	1466	3.25E+07	7.69E+01	2

Table 21. Capacity ranking

I. TECHNICAL FEASIBILITY AND COST OF SYSTEM

Firstly complex next-generation systems rely on new technologies, such as intersatellite links and onboard processing, that are not fully tested yet. New systems, like LEOs and MEOs, may also add new problems such as jitter as they seek to address old issues, including latency. Modeling is important, but the real answers seldom come until equipment is deployed. In this perspective, the recent launch of narrow band systems such as Iridium and Globalstar becomes a very important yardstick, in-particularly to the wide-band LEOs.

Secondly, most satellite systems are billion-dollar ventures with the bulk of funding required upfront without any guarantee of success. To survive, companies need deep pockets or deeper alliances. All this means careful planning to ensure constant funding. LEO systems present additional funding issues because the full constellation must be launched before service can begin, many more satellites are required and these satellites are (constellations must be much larger to cover the globe) expected to burn up in about five years-about half the life cycle of GEOs. That means LEO constellations will be more expensive to maintain, especially in terms of having ready-to-operate spares already in orbit.

³⁰ Considering coverage provided by Spaceway's MEO only

Hughes and Lockheed Martin are generally considered the global satellite market leaders especially with their past experience and current ongoing satellite programs with DOD and many experts think Lockheed's Astrolink and Hughes Spaceway have the technology, funding and breadth to shine.

The author is of the opinion that Teledesic will survive (in spite of the technical hurdles its have to overcome) because of its extremely deep pockets as well as Motorola's reputation of quality. Teledesic's broadband package becomes especially powerful when coupled with global satellite phone services through Motorola's role in Iridium, a service that managed to win two of its own country codes. Although it is narrowband, Iridium also gives Motorola (Teledesic) a head start on the LEO learning curve.

Besides Teledesic, Loral Cyberstar is another system which will also have the same learning curve experience (even though Loral is GEOs) due to its Globalstar venture with QUALCOMM, a constellation that is expected to be one of Iridium's chief competitors. The other strong point of Loral is its aggressive purchasing and partnering strategies as discussed in Chapter IV.

Loral cross-investment partner, Alcatel's SkyBridge relies on more traditional bent-pipe and Ku frequencies for its LEO constellation, it will not be allowed to interfere with existing GEO services. Before the SkyBridge LEO comes into an arc where it might cause interference, it has to direct its transmission down to an earth station and back up to a companion satellite also serving the destination area; a process estimated to incur a 20-millisecond delay. The logic behind using Ku, rather than Ka, is its fewer issues with rain fade and that the satellites will be compatible with existing terrestrial infrastructure. Additionally, ground equipment is also cheaper, more stable and more readily available.

With the above discussion, a ranking assessment based on the risk involved in each factor is compiled and tabled as follows:

	Freq band	Intersatellite link	Experience	Bentpipe / onboard processing	Cost of system based on type of constellation	Ranking
Teledesic (LEO)	Ka	Yes	Iridium	On board processing	9 billion (LEO)	5
Astrolink (GEO)	Ka	Yes	Milstar	On board processing	6 billion (GEO)	3
Cyberstar (GEO)	Ka and Ku	No	Globalstar	Bent-pipe	~ 2.6 billion (GEO)	1
Spaceway ³¹ (GEO- MEO hybrid)	Ka	Yes	Global Broadcast Service	On board processing	~7.7 billion (GEO-MEO)	4
Skybridge (LEO)	Ku	No	Unknown but using tested technology	Bent-pipe	4.3 billion (LEO)	2

Table 22. Ranking with respect to Technical feasibility and cost of system

J. SUMMARY

The hurdles still awaiting most broadband satellite players are many, so there is general agreement that an industry bloodbath is inevitable. Before 2002 arrives, the list of broadband players will be both consolidated and weak ones weeded out. To name a few, where the projects have either been discontinued or absorbed into another system are Motorola M-star and Celestri as well as AT&T Voicespan. When acquiring any system for Military usage, the author opts that a low risk system is most preferred, as this will determine the success, survivability of these systems as well as the potential impact on the military if these systems either fail or deny to provide services to DOD.

Table 23 illustrated the ranking of each system, factors related to risks involved are given three times higher weightage than the rest. However, the ranking deduced and weighting factor allocated are not bound by any hard evidence and will change when each system, market and

³¹ Considering coverage provided by Spaceway's MEO only

military situation evolved through time. At this junction of assessment, Teledesic demonstrates to be the most preferred out of the five systems under study.

Reqs	Teledesic	Astrolink	Cyberstar	Spaceway	Skybridge
Factors relate to risk involved					
Access and Control	2	1	3	1	4
Regulatory approval	1	3	3	3	2
Technical feasibility and cost of system	5	3	1	4	2
Score	8	7	7	8	8
Ranking	2	1	1	2	2
Factors relate to performance and affordability					
Coverage	1	3	4	3	2
Market acceptance	1	2	2	2	1
Quality of Service	1	4	4	3	2
Capacity	1	4	5	3	2
Inter-operability	1	2	2	1	1
Score	5	15	17	12	8
Ranking	1	4	5	3	2
Score based on low risk is of 3 times more preferred than performance and affordability					
	$8 \times 3 + 5 = 28$	$7 \times 3 + 15 = 36$	$7 \times 3 + 17 = 38$	$8 \times 3 + 12 = 35$	$8 \times 3 + 8 = 32$
System Ranking	1	4	5	3	2

Table 23. System ranking

VI. CONCLUSIONS

This thesis does not attempt to provide an all-inclusive list of commercial wide-band selection criteria or to directly quantifying their relative merits for military usage. This research study however intends to serves as a point of departure for future commercial wide-band selection discussions and allows the reader to recognize that the selection of commercial SATCOM services is a multi-variable decision. At this point of assessment, some candidates may appear to out-perform the rest or are more politically acceptable. However at this early stage it is difficult to predict which of these system will survive given most are utilizing unproven technology as well as the fluidity nature of this competitive market. Thus they have to be critically examined when more concrete information is available and when the market becomes more visible. None-the-less, based on this initial screening process, the author is of the opinion that the inherent vulnerabilities associated with these systems preclude their use in most military applications until their vulnerabilities can be effectively mitigated or eliminated. To utilize these systems for tactical or strategic applications involves an element of risk that may or may not be justified if other military communication systems are available to satisfy the requirement.

A. POTENTIAL MISSION

Emerging applications of wide-band system include battlefield situation awareness, operational planning and execution, weather, telemedicine, operational and maintenance support, tailored intelligence, distance learning, training, morale, welfare and recreational services. The assignment of a SATCOM requirement to a military owned SATCOM or COMMERSAT system is dependent on the criticality of the information, the survivability required of the circuit in accomplishing a particular mission and the availability of satellite resources. These requirements can be assigned to MILSATCOM or commercial satellite systems based on the type of protection required (if any) for the circuit. DOD communication can be divided into three categories [Ref. 13] as follow.

- Basic C2 circuits critical to tactical and strategic decision making and the successful coordination of operations that typically must have the protection abilities afforded by MILSATCOM.
- Operational and tactical circuits that may or may not require protection from jamming and LPI/LPD capabilities. Allocation should be based on the technical capabilities of the foe, the loading factor of MILSATCOM assets in the theater, the assigned mission of the units and the tactical environment. As the mission(s) and tactical conditions change, the circuits can be reallocated to meet new operational security requirements. Depending on the mission and tactical environment, these circuits will benefit from the greater bandwidths available on COMMERSAT systems or can be allocated to COMMERSAT systems to reserve MILSATCOM bandwidth for higher priority circuits.
- Support circuits that include logistics, medical and moral support for soldiers as well as for peace keeping, humanitarian and military support to civilian authorities will typically be allocated to COMMERSAT systems, but may be reallocated to MILSATCOM systems for specific missions.

In summary, some of the military services that may be leveraged by Commercial Wide band SATCOM are as follows.

- Complimentary Capacity
- Surge Resource
- High speed data
- Video Tele-Conferencing
- Mission support
 - Sensor to Shooter
 - Primary Imagery

- Tomahawk Planning
- Tele-medicine/Training

B. LIMITATIONS AND RECOMMENDATIONS

Based on the potential mission as recommended in [Ref. 13] and the media mix requirements allocation as projected by Naval Space Command [Ref. 12] (shown in Figure 9), a huge portion of the "Must be SATCOM" requirement will be apportioned to commercial wide band satellite system. Thus it will be inevitable that COMMERSAT systems will be engaged for sensitive information transfer. However all five proposed system have several limitations that are of importance to military planners. As discussed in Chapter II and section A of this chapter, the principal limitation is the general lack of protective features such as Anti-Jam (AJ), Anti-Scintillation (AS), and Low Probability of Detection and Interception, even though COMMERSAT might provide some of these capabilities due to a particular system design or configuration. Therefore for DOD SATCOM requirements that do not need to meet this set of protection attributes are able to utilize COMMERSAT systems. With regards to communication and information security, an emerging technology known as Virtual Private Network (VPN) could be adapted, such that DOD will has its own private network that span throughout the globe, by using the wide-band satellite network as a carrier. This technology restricts traffic so that data packets can travel only between DOD sites or users. Furthermore, even if an outsider accidentally receives a copy of a packet, VPN technology means that they cannot understand the contents. To build a VPN, DOD has to buy or build a special hardware and software system for each site that is conforms to both DOD and Wide-band satellite network protocols and standards. The system is placed between the site's private network (serving one or a number of DOD users) and the satellite network. Each of the system must be configured with the addresses of DOD's other VPN systems. The software will then exchange packets only with the VPN system at the DOD's other sites. Furthermore to increase privacy, VPN can encrypts each

packet before transmission such as using the KG-95³². Note these measures are on top of what presumably the inherent system security protecting the integrity of its wide-band satellite network.

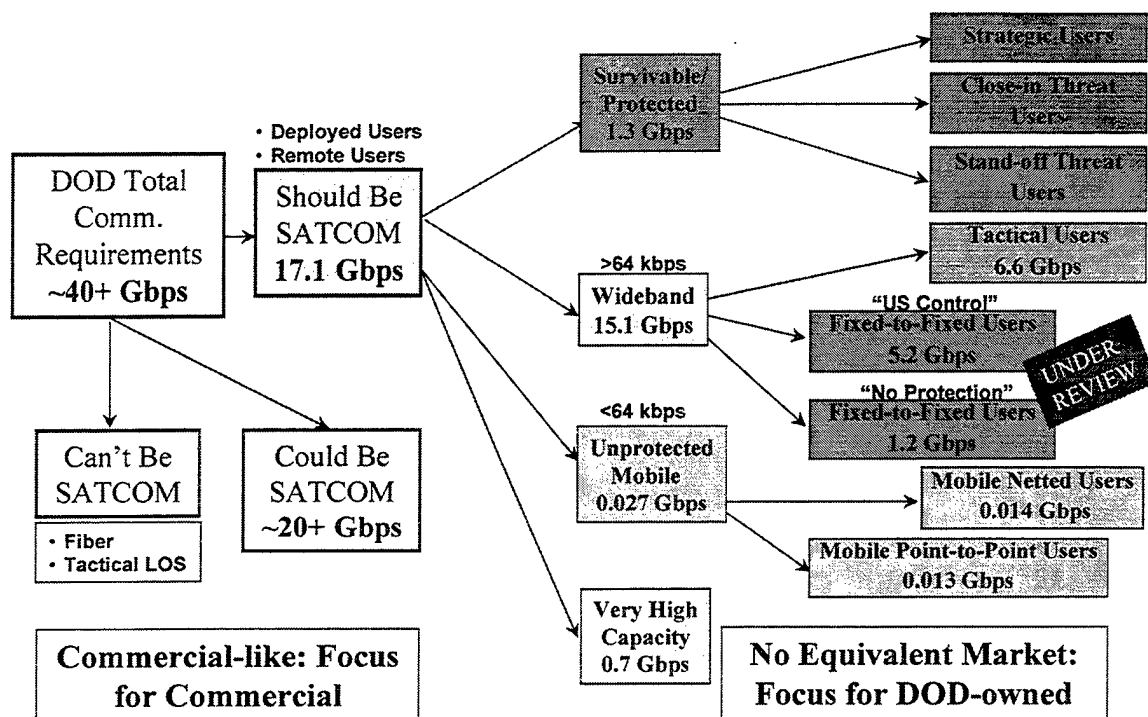


Figure 9. Media Mix Requirements Allocation from [Ref.12]

Additionally, physical protection of fixed and deployable satellite control centers and gateways is another point of concern since these are most vulnerable in varying degrees to conventional attack. Physical securities of critical gateways have to be enhanced to mitigate the possibility of loss to a terrorist attack or natural disaster. Possible measures to be considered include blast hardening, perimeter alarms and security forces.

Besides the security and protection issues, most of the systems (if not all) proposed have to augment with additional satellites or relay sites since most only provide coverage over landmass and are most likely not able to provide polar coverage and users under combat

³² The KG-95 is a family of full duplex, fixed plant, bulk encryption/decryption key generators that are approved for processing all classifications of traffic.

environment such as double canopy etc. Support and operation of these satellites would require additional telemetry, tracking and control capabilities and specialized gateways.

As the use of commercial SATCOMs increases throughout DOD, basic interoperability among earth terminals have to be established and maintained through the use of appropriate standards, and in a manner consistent with advancing commercial technology, to a practical extent, a universal terminal is most desirable.

To mitigate these limitations, upon DOD embarking on the use of any of these commercial wide-band systems, full co-operation and regular communication between DOD and the service providers are necessary to ensure DOD requirements are considered in the design and pre-launch planning phases of commercial spacecraft.

LIST OF REFERENCES

1. William B.Scott, *Multimedia Satcom Competition Intensifies*, Aviation Week & Space Technology, April 13, 1998
2. Steven G. Miller, *DOD SATCOM Requirements – The Analytical Process*, DISA/D216
3. <http://www.acq.osd.mil/space>
4. *C4I Handbook for Integrated Planning*, May 96
5. *The Demand for SATCOM Today and in the Future*, J6 briefing slides
6. *Naval SATCOM Systems and Applications* (SS4900 course note)
7. Darin L. Powers, *Required Performance Parameters for Naval Use of Commercial Wide-band SATCOM*, NPS thesis, Sept 98
8. *Joint Mobile User SATCOM Study (MUS) report*, N-6B and PEO-SCS, Feb 98
9. <http://www.intelsat.com>
10. Christy Hudgins-Bonafield, *Networking in the 21st Century: The Sky's the Limit*, <http://www.networkcomputing.com/905/905f2.html>
11. Booz Allen & Hamilton, *Assessing Commercial Satellite Communication Systems*, Summer 97
12. CDR D.A.Baciocco, *Satellite Communications for the 21st Century*, USN, <http://www.acq.osd.mil/space/architect/>
13. *Executive Summary of the Commercial Satellite Communications (SATCOM) Report*, <http://www.fas.org/spp/military/docops/navy/commrept/index.html>
14. John Montgomery, *The Orbiting Internet: Fiber in the Sky*, <http://www.byte.com/art/9711/sec5/art1.htm#117cova2>
15. Teledesic web page, <http://www.teledesic.com/>
16. Rappaport, *Wireless Communications*, Prentice Hall, 1996
17. Paul Rohan, *Introduction to Electronic Wave Propagation*, Artech House, 91

BIBLIOGRAPHY

- Blanchard, *Systems Engineering and Analysis*, Prentice Hall, 1997
- Cary Reese Stone, *Integration Of Commercial Mobile Satellite Services Into Naval Communications*, Thesis NPS, Sept 97
- Dana L. Haskell, *An Analysis Of Commercial Low Earth Orbit And Medium Earth Orbit Mobile Satellite Systems And Their Potential For Military Use*, Thesis NPS, Sept 96
- David R. Bradley, *A Requirement Analysis Of The 2008 MILSATCOM Architecture*, Thesis NPS, Sept 97
- Debora Russell & G.T. Gangemi Sr, *Computer Security Basics*, O'Reilly & Associates, Inc
- Douglas E. Comer, *Computer Network and Internet 2nd edition*, Prentice Hall, 1999
- <http://www.analysys.com/scripts/satellite.exe?pto=info>
- <http://www.astrolink.com/index.html>
- <http://www.cyberstarcom.com/>
- <http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/>
- <http://www.fas.org/spp/military/program/com/index.html>
- <http://www.inmarsat.org/index3.html>
- <http://www.ptc.org/pub/ptr/sept95/spaceway.html>
- <http://www.satmagazine.com/>
- <http://www.skybridgesatellite.com/w.htm>
- <http://www.spaceway.com/>
- Low-Earth-Orbit Satellite Networks*, http://www.biz.uiowa.edu/class/6k180_park/student-reports/kburrows/
- Naval Space Command. Naval Warfighter's Guide To Space*, Nov 96
- Nicholas M. Homan, *A Military UHF Communications Satellite Design For The User On The Move*, Thesis NPS, Dec 1997
- Pritchard, *Satellite Communication Systems Engineering 2nd edition*, Prentice Hall, 1993
- Roger L. Freeman, *Telecommunications Transmission handbook 4th edition*, Wiley, 1998

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Program.....2
8725 John J. Kingman Rd., STE 0944
Ft. Belvoir, Virginia 22060-6218

2. Dudley Knox Library.....2
Naval Postgraduate school
411 Dyer Road
Monterey, California 93943-5101

3. Professor Brig Agrawal.....1
Code AA/Ag
Naval Postgraduate School
Monterey, California 93943-5101

4. Professor Craig Baldwin.....1
Code AA/Ba
Naval Postgraduate School
Monterey, California 93943-5101

5. Professor Donald v. Z. Wadsworth.....1
Code EC/Wd
Naval Postgraduate School
Monterey, California 93943-5101

6. Chairman, Information Warfare Academic Group.....1
Code IW
Naval Postgraduate School
Monterey, California 93943-5101

7. Head, Department of Strategic Studies 1
SAFTI Military Institute
Ministry of Defense
500 Upper Jurong Road
S638364
Singapore

8. Major Lee, Tin Hua.....1
Blk 312, Yishun Ring Road
#05-1212, S(760312)
Singapore